JC17 Rec'd PCT/PTO 01 JUN 2001

FORM PTO-1390 US DEPARTMENT OF COMMERCE REV. 5-93 PATENT AND TRADEMARK OFFICE **TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371**		ATTORNEYS DOCKET NUMBER **P01,0158** U.S. APPLICATION NO. (if known, see 37 CFR 1.5) 09/857281
INTERNATIONAL APPLICATION NO. **PCT/DE99/03825**	INTERNATIONAL FILING DATE **01 DECEMBER 1999**	PRIORITY DATE CLAIMED **03 DECEMBER 1998**

TITLE OF INVENTION
METHOD AND ARRANGEMENT FOR DESIGNING A TECHNICAL SYSTEM

APPLICANT(S) FOR DO/EO/US
Stefan SCHÄFFLER et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay.
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☒ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US)
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. §371(c)(3))
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☒ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 C.F.R. 1.97 and 1.98; **(PTO 1449, Prior Art, Search Report, 10 References)**.
12. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 C.F.R. 3.28 and 3.31 is included. **(SEE ATTACHED ENVELOPE)**
13. ☒ Amendment "A" Prior to Action and Appendix "A".
    ☐ A SECOND or SUBSEQUENT preliminary amendment.
14. ☒ A substitute specification and substitute specification mark-up.
15. ☒ A change of address letter attached to the Declaration.
16. ☒ Other items or information:
    a. ☒ Submission of Drawings, 3 sheets of drawings, Figures 1-5
    b. ☒ Appointment of Associate Power of Attorney
    c. ☒ EXPRESS MAIL #EL 843728169 US dated June 1, 2001

JC18 Rec'd PCT/PTO

U S APPLICATION NO. 09/857281	INTERNATIONAL APPLICATION NO PCT/DE99/03825	ATTORNEY'S DOCKET NUMBER P01,0158

				CALCULATIONS	PTO USE ONLY
17. ☒ The following fees are submitted: **BASIC NATIONAL FEE (37 C.F.R. 1.492(a)(1)-(5):** Search Report has been prepared by the EPO or JPO $860.00 International preliminary examination fee paid to USPTO (37 C F R. 1.482) $690.00 No international preliminary examination fee paid to USPTO (37 C.F.R. 1.482) but international search fee paid to USPTO (37 C.F.R. 1.445(a)(2) $710.00 Neither international preliminary examination fee (37 C F R. 1.482) nor international search fee (37 C.F.R. 1.445(a)(2) paid to USPTO $1000 00 International preliminary examination fee paid to USPTO (37 C.F.R. 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) $ 100.00					
ENTER APPROPRIATE BASIC FEE AMOUNT =				$ 860.00	
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 C.F.R. 1 492(e)).				$	
Claims	Number Filed	Number Extra	Rate		
Total Claims	10 - 20 =	0	X $ 18.00	$	
Independent Claims	02 - 3 =	0	X $ 80.00	$	
Multiple Dependent Claims			$270.00 +	$	
TOTAL OF ABOVE CALCULATIONS =				$ 860.00	
Reduction by ½ for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (Note 37 C.F.R. 1.9, 1.27, 1.28)				$	
SUBTOTAL =				$ 860.00	
Processing fee of $130.00 for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$	
TOTAL NATIONAL FEE =				$ 860.00	
Fee for recording the enclosed assignment (37 C.F.R. 1.21(h). The assignment must be accompanied by an appropriate cover sheet (37 C.F.R. 3.28, 3.31). $40.00 per property +					
TOTAL FEES ENCLOSED =				$ 860.00	
				Amount to be refunded	$
				charged	$

a. ☒ A check in the amount of $ 860.00 to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. __________ in the amount of $ _______ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 50-1519. **A duplicate copy of this sheet is enclosed.**

NOTE: Where an appropriate time limit under 37 C.F.R. 1.494 or 1.495 has not been met, a petition to revive (37 C.F.R. 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

SCHIFF HARDIN & WAITE
PATENT DEPARTMENT
6600 Sears Tower
233 South Wacker Drive
Chicago, Illinois 60606-6473

CUSTOMER NUMBER 26574

Mark Bergner
SIGNATURE

Mark Bergner
NAME

45,877
Registration Number

BOX PCT
IN THE UNITED STATES DESIGNATED/ELECTED OFFICE
OF THE UNITED STATES PATENT AND TRADEMARK OFFICE
UNDER THE PATENT COOPERATION TREATY--CHAPTER II

PRELIMINARY AMENDMENT A
PRIOR TO ACTION

APPLICANT(S):	Stefan SCHÄFFLER et al
ATTORNEY DOCKET NO.:	P01,0158
INTERNATIONAL APPLICATION NO:	PCT/DE99/03825
INTERNATIONAL FILING DATE:	01 December 1999
INVENTION:	METHOD AND ARRANGEMENT FOR DESIGNING A TECHNICAL SYSTEM

Assistant Commissioner for Patents,
Washington D.C. 20231

Sir:

Applicants herewith amend the above-referenced PCT application, and request entry of the Amendment prior to examination on the United States Examination Phase.

IN THE CLAIMS:

On page 21:

replace line 1 with --WHAT IS CLAIMED IS:--;

Please replace original claims 1-10 with the following rewritten claims 1-10, referring to the mark-ups in Appendix A.

1. (Amended) A method for designing a technical system, comprising the steps of:

a) providing a substitute model that describes measurement data of a predetermined system;

b) determining a numerical value for a quality of said substitute model by comparing said measurement data of said predetermined system with data determined by said substitute model;

c) adapting said substitute model from said numerical value for said quality to be as high of a quality as possible;

d) applying said substitute model adapted with regard to its quality in a design of said technical system.

2. (Amended) The method as claimed in claim 1, wherein said substitute model is a regression model.

3. (Amended) The method as claimed in claim 1, wherein said step of determining a numerical value for a quality further utilizes a mean square deviation of said measurement data from said data determined by said substitute model.

4. (Amended) The method as claimed in claim 1, further comprising the step of:

sorting said measurement data according to their quality, with respect to the deviation of the latter from said data determined by said substitute model; and

picking out a predetermined number of n% of worst measurement data.

5. (Amended) The method as claimed in claim 1, further comprising the step of:

sorting said measurement data according to their quality, with respect to the deviation of the latter from said data determined by said substitute model; and

picking out a predetermined number of n% of worst measurement data unless this data lie in a continuous range.

6. (Amended) The method as claimed in claim 1, further comprising the step of:

reducing an amount of measurement data in the course of a preprocessing operation.

7. (Amended) The method as claimed in claim 6, further comprising the step of:

classifying, in which said preprocessing operation, of said measurement data.

8. (Amended) The method as claimed in claim 1, further comprising the step of:

controlling a technical plant utilizing said data obtained by designing.

9. (Amended) The method as claimed in claim 8, further comprising the step of:

online adapting control for said technical plant.

10. (Amended) An arrangement for designing a technical system, comprising:

a processor unit which is set up in such a way that

a) measurement data of a predetermined system are described based on a substitute model and stored in said processor unit;

b) a numerical value for a quality of said substitute model is determined by said processor unit by comparing said measurement data of the predetermined system with data determined by said substitute model; and

c) said substitute model is adapted, utilizing said processor unit, from said numerical value for said quality to be as of high a quality as possible, wherein said substitute model adapted with regard to its quality is used for designing said technical system.

REMARKS

The present Amendment revises the specification and claims to conform to United States patent practice, before examination of the present PCT application in the United States National Examination Phase. Pursuant to 37 CFR 1.125 (b), applicants have concurrently submitted a substitute specification, excluding the claims, and provided a marked-up copy. All of the changes are editorial and applicant believes no new matter is added thereby. The amendment, addition, and/or cancellation of claims is not intended to be a surrender of any of the subject matter of those claims.

Early examination on the merits is respectfully requested.

Submitted by,

Mark Bergner (Reg. No. 45,877)

Mark Bergner
Schiff Hardin & Waite
Patent Department
6600 Sears Tower
233 South Wacker Drive
Chicago, Illinois 60606-6473
(312) 258-5779
Attorneys for Applicant

CUSTOMER NUMBER 26574

Appendix A
Mark Ups for Claim Amendments

This redlined draft, generated by CompareRite (TM) - The Instant Redliner, shows the differences between - original document : Q:\DOCUMENTS\YEAR 2001\P010158-SCHAEFFLER-DESIGNING A TECHNICAL SYSTEM\ORIGINAL CLAIMS.DOC
and revised document: Q:\DOCUMENTS\YEAR 2001\P010158-SCHAEFFLER-DESIGNING A TECHNICAL SYSTEM\AMENDED CLAIMS.DOC

CompareRite found 71 change(s) in the text

Deletions appear as Overstrike text surrounded by []
Additions appear as Bold-Underline text

1. **(Amended)** A method for designing a technical system, **comprising the steps of:**

a) providing a substitute model that describes ~~[a) in which]~~ measurement data of a predetermined system ~~[are described on the basis of a substitute model;]~~**;**

~~[b) in which]~~ **b) determining** a numerical value for ~~[the]~~ **a** quality of ~~[the]~~ **said** substitute model ~~[is determined]~~ by comparing ~~[the]~~ **said** measurement data of ~~[the]~~ **said** predetermined system with data determined by ~~[the]~~ **said** substitute model;

c) ~~[in which the]~~ **adapting said** substitute model ~~[is adapted]~~ from ~~[the]~~ **said** numerical value for ~~[the]~~ **said** quality to be ~~[of]~~ as high **of** a quality as possible;

d) ~~[in which the]~~ **applying said** substitute model adapted with regard to its quality ~~[is used for designing the]~~ **in a design of said** technical system.

2. **(Amended)** The method as claimed in claim 1, ~~[in which the]~~ **wherein said** substitute model is a regression model.

3. **(Amended)** The method as claimed in claim 1 ~~[or 2, in which the]~~**, wherein said step of determining a numerical value for a** quality ~~[is determined on the basis of]~~ **further utilizes** a mean square deviation of ~~[the]~~ **said** measurement data from ~~[the]~~ **said** data determined by ~~[the]~~ **said** substitute model.

4. **(Amended)** The method as claimed in ~~[one of the preceding claims, in which the]~~ **claim 1, further comprising the step of:**

sorting said measurement data ~~[are sorted]~~ according to their quality, with respect to the deviation of the latter from ~~[the]~~ **said** data determined by ~~[the]~~ **said** substitute model~~[,]~~**;** and

picking out a predetermined number of n% of ~~[the]~~ worst measurement data ~~[are picked out]~~.

5. **(Amended)** The method as claimed in claim ~~[4, in which the n% of the]~~**1, further comprising the step of:**

sorting said measurement data according to their quality, with respect to the deviation of the latter from said data determined by said substitute model; and

picking out a predetermined number of n% of worst measurement data **unless this data** ~~[are not picked out if they]~~ lie in a continuous range.

6. **(Amended)** The method as claimed in ~~[one of the preceding claims, in which the]~~ **claim 1, further comprising the step of:**

reducing an amount of measurement data ~~[is reduced]~~ in the course of a preprocessing operation.

7. **(Amended)** The method as claimed in claim 6, ~~[in which the]~~**further comprising the step of:**

classifying, in which said preprocessing operation ~~[comprises a classification of the]~~**, of said** measurement data.

8. **(Amended)** The method as claimed in ~~[one of the preceding claims, in which the]~~ **claim 1, further comprising the step of:**

controlling a technical plant utilizing said data obtained by ~~[means of]~~ designing ~~[are used for controlling a technical plant.]~~**.**

~~[9.]~~**9. (Amended)** The method as claimed in claim 8, ~~[for]~~ **further comprising** the **step of:**

online ~~[adaptation of the]~~ **adapting** control for ~~[the]~~ **said** technical plant.

10. **(Amended)** An arrangement for designing a technical system, ~~[with]~~ **comprising:**

a processor unit which is set up in such a way that

a) measurement data of a predetermined system are described **based** on ~~[the basis of]~~ a substitute model **and stored in said processor unit**;

b) a numerical value for [~~the~~] **a** quality of [~~the~~] **said** substitute model is determined by **said processor unit by** comparing [~~the~~] **said** measurement data of the predetermined system with data determined by [~~the~~] **said** substitute model; **and**

c) [~~the~~] **said** substitute model is adapted [~~from the~~]**, utilizing said processor unit, from said** numerical value for [~~the~~] **said** quality to be **as** of [~~as~~] high a quality as possible**, wherein said**[~~;~~

~~the~~] substitute model adapted with regard to its quality is used for designing [~~the~~] **said** technical system.

This redlined draft, generated by CompareRite (TM) - The Instant Redliner, shows the differences between -

original document : Q:\DOCUMENTS\YEAR 2001\P010158-SCHAEFFLER-DESIGNING A TECHNICAL SYSTEM\ORIGINAL SPECIFICATION.DOC

and revised document: Q:\DOCUMENTS\YEAR 2001\P010158-SCHAEFFLER-DESIGNING A TECHNICAL SYSTEM\SUBSTITUTE SPECIFICATION.DOC

CompareRite found 159 change(s) in the text

Deletions appear as Overstrike text surrounded by []

Additions appear as Bold-Underline text

SPECIFICATION

TITLE ~~[DESCRIPTION]~~

METHOD AND ARRANGEMENT FOR DESIGNING A TECHNICAL SYSTEM

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The invention relates to a method and arrangement for designing a technical system.

Description of the Related Art

[0002] The system behavior of a technical system, for example, a process engineering plant or system in heavy industry, depends on numerous parameters. In the course of designing such a system, ~~[that is in particular]~~ **particularly** in the case of a new design or when adapting or adjusting an already existing system, it is necessary to comply with preconditions~~[, for example with regard to]~~ **such as** the cost-effectiveness or environmental impact of the system. Each precondition is formulated as a target function, the ~~[optimization of which with regard]~~ **general aim being to optimize this with respect** to the other target functions ~~[is the general aim.~~

~~]~~.

SUMMARY OF THE INVENTION

[0003] The object of the invention is to make it possible for a technical system to be designed on the basis of measurement data of a predetermined system. Specifically with regard to the optimization of the existing system or with regard to an optimized new design of a system, such use of known measurement data is of great significance.

[0004] This object is achieved ~~[according to the features of the independent patent claims. Developments of the invention also emerge from the dependent claims.~~

~~]~~**a method and apparatus described below.**

[0005] To achieve the object, **the present invention provides** a method for designing a technical system in which measurement data of a predetermined system are described on the basis of a substitute model ~~[is specified]~~. A numerical value for the quality of the substitute model is determined by comparing the measurement data of the predetermined system with data determined by the substitute model. ~~[On the basis of]~~ **Based on** the numerical value for the quality, the substitute model is adapted to be of as high a quality as possible.

[0006] The substitute model adapted with regard to its quality is used for designing the technical system.

[0007] The measurement data obtained from many different realized systems are used for describing the substitute model. ~~[With the]~~ **The** substitute model ~~[it is attempted]~~ **attempts** to replicate the predetermined system as well as possible. The numerical value for the quality of the replication is determined by comparing the actual measurement data with the data obtained on the basis of the substitute model. A great difference between the measurement data and the data of the substitute model corresponds to poor quality, that is**, a** poor mapping of the predetermined system into the substitute model. The numerical value for the quality is used to adapt the substitute model to make the quality itself become as high as possible and consequently to make the substitute model describe the predetermined system as well as possible. The high-quality substitute model obtained in this way is used for designing the technical system.

[0008] Designing is understood in a general sense as meaning both the new design of a technical system and the adaptation of an already existing technical system.

[0009] One development comprises that the substitute model is a regression model. The regression model is based on the description

[0010] $Y_i = f_\beta(x_i) + e_i$

[0011] where

[0012] (y_i, x_i) denotes predetermined pairs of values,

[0013] f_β denotes a function which is dependent on a parameter β, and

[0014] e_i denotes an error.

[0015] It is then intended to minimize the error (as a function of β):

$$\sum_{i=1}^{n} e_i^2 = \varphi(\beta).$$

[0016]

[0017] If the following example

[0018] $Y = \beta_0 + \beta_1 x + \beta_2 x^2 + e$

[0019] is taken as a basis, the functional relationship is of a quadratic order, while the regression model (function, dependent on β) is linear.

[0020] In another development, the quality can be determined on the basis of a mean square deviation of the measurement data from the data determined by the substitute model. The adaptation of the substitute model takes place by minimizing the mean square deviation.

[0021] One refinement comprises that the measurement data are sorted according to their quality, with respect to the deviation of the latter from the data determined by the substitute model, and a predetermined number of n% of the worst measurement data are picked out. Consequently, a quality is determined for each item of measurement data, the volume of measurement data, preferably in the form of a list, being sorted according to their quality and the n% of the worst measurement data, or the n worst measurement data, being picked out. In particular, it must be checked whether the n% of worst measurement data or n worst measurement data lie in a continuous range. If this is the case, these measurement data are not picked out, since they very probably do not represent measurement errors but a continuous range which is not mapped accurately enough by the substitute model.

[0022] Another development ~~[comrises]~~ **comprises** that the ~~[measure-ment]~~ **measurement** data are subjected to a preprocessing operation. Since, in an actual predetermined system, a large amount of measurement data occur per unit of time, it is advisable to subject these measurement data to a preprocessing operation and consequently ensure that largely significant measurement data are taken for forming the substitute model. The preprocessing operation preferably finds its expression in a reduction in the number of measurement data.

[0023] In the process, the measurement data are divided into classes according to predetermined criteria. The measured values of a class are assessed and those measured values for which the assessment lies below a predetermined first threshold value are picked out. The picking out of the measured values results in a reduction with regard to the number of measured values. This results in a significantly reduced number of measured values for a further processing

operation. The further processing operation can take place with less computing effort in comparison with the unreduced number of measured values.

[0024] The classes themselves can also be assessed. In particular, a class for which the assessment lies below a predetermined second threshold value can be picked out. As a result, an additional reduction of the number of measured values is obtained.

[0025] Another development of the preprocessing operation comprises that a criterion for the classification is that, for each class, measured values are determined as a default for setting parameters of the technical system. The technical system is typically set on the basis of a predetermined number of setting parameters; after setting, a reaction of the system to the setting parameters takes place (usually with a time delay) (transient response, transient phenomenon of the system). After setting, consequently a certain set of measured values which can be assigned to the transient phenomenon are recorded, with measured values continuing to occur after the transient phenomenon has come to an end (transition to steady-state operation), and are assigned to the predetermined set of setting parameters. ~~[By adjusting]~~ **Adjusting** the setting parameters~~[,]~~ **determines** a new class ~~[is determined]~~. All **of** the measured values which respectively occur after adjustment of the setting parameters belong in a class of their own.

[0026] In addition, measured values of a class which can be assigned to the respective transient phenomenon can be picked out. Furthermore, erroneous measured values can be picked out. The setting of large technical systems is in many cases directed at long-term steady-state operation. It is advisable for the measured values which relate to the transient phenomenon (of short duration in relation to the steady-state

operation after the transient phenomenon has come to an end) to be picked out, since they have the effect of falsifying measured values for steady-state operation. In particular, when modeling the technical system, the measurement data of the steady-state behavior of the system are of interest.

[0027] One refinement comprises reducing the number of measured values in a class by determining at least one representative value for the measured values of the class. Such a representative value may be:

a) a mean value (for example a sliding mean value) of the measured values of the class,

b) a maximum value of the measured values of the class,

c) a minimum value of the measured values of the class,

d) a median.

[0028] In the case of variant d), one advantage is that a value which actually exists can always be determined, whereas the mean value a) does not itself occur as a value.

[0029] Depending on the application, a suitable choice can be made for determining the representative value of a class.

[0030] An entire class with measured values may be picked out if it contains less than a predetermined number of measured values.

[0031] Another refinement comprises that those measured values which vary by more than a predetermined threshold value from a predeterminable value are picked out. The predeterminable value may be a mean value of all the measured values of the class or a measured value to be expected in response to the respective setting parameters of the technical system.

[0032] Within another development, the data obtained by

~~[means]~~ **way** of designing are used for controlling a technical plant. In addition, the controlling of the technical plant can take place at the running time of the system~~[, that is online.~~

~~]~~ **(i.e., online).**

[0033] Also specified for achieving the object is an arrangement for designing a technical system which has a processor unit~~[, which processor unit is]~~ set up ~~[in]~~ such ~~[a way]~~ that measurement data of a predetermined system can be described on the basis of a substitute model. A numerical value for the quality of the substitute model can be determined by comparing the measurement data of the predetermined system with data determined by the substitute model. On the basis of the numerical value for the quality, the substitute model is adapted to be of as high a quality as possible. The substitute model adapted with regard to its quality is used for designing the technical system.

[0034] This arrangement is particularly suitable for carrying out the method according to the invention or one of its developments explained above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] Exemplary embodiments of the invention are presented and explained below with reference to the drawing, ~~[~~

~~]~~in which:

~~[figure 1 shows]~~**[0036]** **Figure 1 is** a block diagram which contains steps of a method for designing a technical system;

~~[figure 2 shows]~~**[0037]** **Figure 2 is** a schematic diagram of a recovery boiler;

~~[figures 3-5 show input variables, manipulated variables and output]~~**[0038]** **Figure 3 is a chart showing the input** variables of the recovery boiler~~[.]~~**;**

~~[Represented in figure 1 is]~~ **[0039] Figure 4 is a chart showing the manipulated variables of the recovery boiler; and**

[0040] Figure 5 is a chart showing the output variables of the recovery boiler.

DETAILED DESCRIPTION OF THE INVENTION

[0041] Figure 1 shows a block diagram which contains steps of a method for designing a technical system. In a step 101, a substitute model **(preferably a regression model)** is formed on the basis of measurement data. ~~[This substitute model is preferably a regression model.]~~ To adapt the substitute model created in step 101 to the measurement data~~[, that is]~~ **(i.e.,** to perform a refinement of the substitute model~~[,]~~**)** so that the measurement data describe the substitute model in adequate approximation, a numerical value for the quality of the substitute model is determined in a step 102. This numerical value is determined by comparing the measurement data of the predetermined system with data determined by the substitute model. Each item of measurement data preferably receives a numerical value for the quality, which numerical value characterizes the deviation of the item of measurement data from the associated value determined by the substitute model. The sum of all the numerical values for the quality for all the measurement data determines an overall quality for the substitute model. In a step 103, the quality is maximized by minimizing the numerical value for the quality (or a negative quality for the coincidence of the substitute model with the predetermined system). Once an appropriately high quality for the substitute model has been determined, this substitute model is used for designing the technical system in a step 104. The designing may constitute both a new design (cf. step 105) or an adaptation of an already existing technical system (cf. step 106).

[0042] Figure 2 shows a schematic diagram of a recovery boiler. An exemplary embodiment of the method described above is illustrated below on the basis of the example of a "recovery boiler".

[0043] In the paper and pulp industry, various chemicals and also heat and electrical energy are required for the digestion of pulp. The recovery boiler can be used to recover the chemicals used and also thermal energy from a concentrated process liquor (black liquor). ~~[A]~~ **It is decisively significant to** measure ~~[of]~~ the recovery of the chemicals ~~[is of decisive significance]~~ for the cost-effectiveness of the overall plant.

[0044] The black liquor is combusted in a char bed 201. As this happens, an alkali fusion is formed, flowing away via a line 202. In further process steps, the chemicals used are recovered from the constituents of the alkali fusion. Released heat of combustion is used for generating steam. The combustion of the waste liquor and consequently the recovery of the chemicals begins with the atomization of the black liquor via atomizer nozzles 204 into a combustion chamber 203. Particles of the atomized black liquor are dried as they fall through the hot flue gas. The dried liquor particles fall onto the char bed 201, with a first combustion and a chemical reduction taking place. Volatile constituents and reaction products pass into an oxidation zone, in which oxidizing reactions proceed and in which the combustion is completed.

[0045] Important targets for ~~[the]~~ controlling ~~[of]~~ the recovery boiler are the steam production for obtaining energy, the maintaining of emission values from environmental aspects and the efficiency of the chemical reduction.

[0046] The combustion operation, and consequently the targets, are controlled in particular by the air supply on

three levels (Primary Air (PA), Secondary Air (SA), Tertiary Air (TA)). The overall process is subject to numerous influences, which have to be taken into account in the modeling:

a) the measurement of the variables is often subject to strong fluctuations;

b) unmeasured and unmeasurable influencing variables exist;

c) any alteration of the parameters which can be set causes transient phenomena; **and**

d) the technical plant becomes soiled and is cleaned at predetermined intervals, ~~[having the result]~~ **resulting** each time ~~[of]~~ **in** a temporal drift in the system behavior.

[0047] The measured variables of the overall process are divided into input variables (cf. ~~[figure]~~ **Figure** 3) and output variables (cf. ~~[figure]~~ **Figure** 5). Measured values are stored every minute. Four of the input variables are at the same time also manipulated variables (also: parameters which can be set; cf. ~~[figure]~~ **Figure** 4). The manipulated variables are ~~[to be]~~ regarded essentially as free parameters of the overall process which can be set independently of one another. Some of the other input variables are more or less dependent on the manipulated variables. According to one target, in the case of the recovery boiler**,** the "BL Front Pressure" and "BL Back Pressure" variables are always ~~[to be]~~ controlled such that they are the same. The four manipulated variables (cf. ~~[figure]~~ **Figure** 4) are preferably ~~[to be]~~ stored as manipulated variables (with the desired, preset value) and as input variables (with the measured, actual value).

[0048] In the case of the recovery boiler, one problem is

that of meeting targets which**: 1)** are determined in dependence on the parameters to be set**,** and **2)** are defined by ~~[means of]~~ measured variables. A three-stage procedure is chosen here to solve the problem:

1. The targets to be considered are modeled by stochastic methods, these models being updated by new measurements (data-driven, empirical modeling). For this **step** it is advisable to use not just a single model but instead global models for the identification of areas of interest in a parameter space determined by the targets and local models for the exact calculation of optimum operating points. The models used are assessed by measures of quality.

2. If the models considered are not sufficiently accurate (measure of quality) ~~[on account of]~~ **due to** the data situation, new operating points are evaluated on a specific basis to improve the model (experimental design). Furthermore, by the use of global stochastic optimizing methods with respect to the targets, attractive areas are identified in dependence on the current global model.

3. For the local optimization, local models are devised and, if appropriate, the available sets of data are extended on a specific basis (experimental design).

[0049] The targets constitute physical-technical or business-management criteria, which generally have to conform to boundary conditions and/or safety conditions. Often a number of these criteria have to be considered simultaneously. The use of a stochastic model can be used in particular to simulate in the computer the target variables to be optimized and their dependence on the parameters to be set. This is necessary whenever measurements are very cost-intensive or very time-consuming. In the case of safety requirements, possible hazardous situations can be avoided.

[0050] In the case of the recovery boiler, an online optimization which is based on a number of data is necessary because the physical-chemical processes cannot be quantitatively modeled with sufficient accuracy and because the behavior of the plant is subject to fluctuations in the course of operation. Knowledge of this behavior must be continually extended by selective choice of new operating points. Therefore, the already described three-stage procedure of stochastic modeling and mathematical optimization is recommendable as part of online optimization.

DESCRIPTION OF THE INPUT VARIABLES

[0051] The a input variables ($a \in \mathbf{N}$, $\mathbf{N}$: set of natural numbers) are generally dependent on n actuated variables $n \in \mathbf{N}$ and on random effects. They can be described as follows:

[0052] Let (Ω, S, P) be a probability space and $\mathbf{B}^v$ be a Borel σ algebra over $\mathbb{R}^v$ ($\mathbb{R}$: set of real numbers) for each $v \in \mathbf{N}$. The input variables are represented by ~~[means of]~~ a $\mathbf{B}^n \times S - \mathbf{B}^a$-measurable mapping φ:

$$\varphi : \mathbb{R}^n \times \Omega \rightarrow \mathbb{R}^a \qquad (1).$$

[0053] The domain of the mapping φ is a Cartesian product of two sets. If the respective projections onto the individual sets are considered, the following mappings are obtained:

[0054]

$$\varphi_x : \Omega \rightarrow \mathbb{R}^a,\ \omega \rightarrow \varphi(x, \omega) \quad \text{for all} \quad x \in \mathbb{R}^n \qquad (2),$$

[0055]

$$\varphi^{\omega}: \mathbf{R}^n \to \mathbf{R}^a,\ x \to \varphi(x, \omega) \quad \text{for all} \quad \omega \in \Omega \qquad (3).$$

[0056]

$$\left\{\varphi_x;\ x \in \mathbf{R}^n\right\}$$

[0057] ~~[ ]~~ is a stochastic process with an index set

[0059] $\square^n$, and a mapping φ^{ω} is, for each event $\omega \in \Omega$, a path of this stochastic process.

[0060] In the case of the recovery boiler, n=4 and a=14 (after elimination of the "BL Back Pressure" variable).

[0061] On account of the required measurability of the mapping φ_x, for each $x \in \square^n$ the mapping φ_x is a random variable. Under suitable additional preconditions, expectation values and higher moments can be considered. This approach permits the step from stochastic models to deterministic optimization problems. In the case of a deterministic optimization problem, the target function can be set directly by ~~[means of]~~ a variable, whereas the stochastic variable influences the target function but does not permit a specific setting.

DESCRIPTION OF THE OUTPUT VARIABLES

[0062] The process model M of the recovery boiler is described as a function in dependence on the input variables and further random effects. In this case let (Ω, S, P) be the above probability space. The process model M is then a $\mathbf{B}^a \times S$ - $\mathbf{B}^b$-measurable mapping:

[0063]

$$M : \mathbf{R}^a \times \Omega \to \mathbf{R}^b \qquad (4),$$

[0064] where b denotes the number of output variables.

[0065] Since the recovery boiler is subject to a cyclical temporal drift (from cleaning phase to cleaning phase), a description with a time parameter is also conceivable. The output variables can be represented by $\mathcal{B}^n \times S$ - $\mathcal{B}^b$-measurable mappings ψ:

[0066]

$$\psi : \mathbf{R}^n \times \Omega \to \mathbf{R}^b \tag{5}$$,

$$(x, \omega) \to M(\varphi(x, \omega), \omega) \tag{6}$$.

[0067] If the respective projections onto the individual sets of the domain are considered, the following mappings are obtained

[0068]

$$\psi_x : \Omega \to \mathbf{R}^b,\ \omega \to \psi(x, \omega) \quad \text{for all} \quad x \in \mathbf{R}^n \tag{7}$$,

$$\psi^\omega : \mathbf{R}^n \to \mathbf{R}^b,\ x \to \psi(x, \omega) \quad \text{for all} \quad \omega \in \Omega \tag{8}$$.

[0069] [0070] ~~[ ]~~ is a stochastic process with an index set

$$\{\psi_x;\ x \in \mathbf{R}^n\}$$

[0072] □^{n}, and the mapping ψ^ω is, for each $\omega \in \Omega$, a path of this stochastic process.

[0073] In the case of the recovery boiler, b=15.

[0074] The fact that in the definition of ψ a distinction is not drawn between the events ω used does not mean that there is any restriction, since Ω can be represented as a

Cartesian product of an Ω_1 and an Ω_2. The above representation consequently also comprises the model:

[0075]

$$\psi : \mathbf{R}^n \times \Omega_1 \times \Omega_2 \rightarrow \mathbf{R}^b \qquad (9),$$

$$(x, \omega_1, \omega_2) \rightarrow M(\varphi(x, \omega_1), \omega_2) \qquad (10).$$

DESCRIPTION OF THE AVAILABLE SETS OF DATA

[0076] With the descriptions in the two foregoing sections, the input variables and the output variables can be combined together to form measured variables (= measurement data) Φ. Φ is a $\mathcal{B}^n \times \mathcal{S}$ - $\mathcal{B}^m$-measurable mapping with m = a + b and

[0077]

$$\Phi : \mathbf{R}^n \times \Omega \rightarrow \mathbf{R}^m \qquad (11),$$

$$(x, \omega) \rightarrow \begin{pmatrix} \varphi(x, \omega) \\ \psi(x, \omega) \end{pmatrix} \qquad (12).$$

[0078] If the respective projections onto the individual sets of the domain are again considered, the following mappings are obtained:

$$\Phi_x : \Omega \rightarrow \mathbf{R}^m,\ \omega \rightarrow \Phi(x, \omega) \quad \text{for all} \quad x \in \mathbf{R}^n \qquad (13),$$

$$\Phi^\omega : \mathbf{R}^n \rightarrow \mathbf{R}^m,\ x \rightarrow \Phi(x, \omega) \quad \text{for all} \quad \omega \in \Omega \qquad (14).$$

~~[ ]~~[0079] [0080] is a stochastic process with an index set

$$\{\Phi_x;\ x \in \mathbb{R}^n\}$$

[0082] $\mathbb{R}^n$, and the mapping Φ^ω is, for each $\omega \in \Omega$, a path of this stochastic process.

[0083] For each chosen related variable tupel x, in the case of the recovery boiler many realizations of Φ_x are determined and stored, i.e., for each $x_j \in \mathbb{R}^n$ numerous realizations

[0084]

$$\Phi_{jk} := \Phi(x_j, \omega_{jk}) \tag{15}$$

$$\text{with} \quad \omega_{jk} \in \Omega;\ k = 1,2,\ldots,v_j;$$

$$v_j \in \mathbf{N};\ j = 1,2,\ldots,u;\ u \in \mathbf{N}$$

[0085] are considered. The stored sets of data D_{jk} of the recovery boiler are consequently (n+m) tupels:

[0086]

$$D_{jk} = \begin{pmatrix} x_j \\ \Phi_{jk} \end{pmatrix}, \quad k = 1,2,\ldots,v_j;\ j = 1,2,\ldots,u \tag{16}.$$

[0087] In this case, D_{j1k1} is stored before D_{j2k2} if

[0088]

$$(j_1 < j_2) \vee ((j_1 = j_2) \wedge (k_1 < k_2))$$

[0089] applies.

DATA COMPRESSION BY CLASSIFICATION OF THE PARAMETERS

[0090] Since for each manipulated variable tupel x there

are generally a number of realizations of Φ_x, a classification of the parameters by forming arithmetic mean values is a suitable operation as a first step of the statistical data analysis on account of the complex stochastic properties of the process to be considered. Moreover, sets of data which are obviously erroneous are picked out. A set of data which is obviously erroneous is, for example, a physically impossible measurement which cannot occur in reality, ~~[in particular on account of]~~ **particularly due to** a setting made.

[0091] Procedure:

1. Sets of data in which the "BL Front Pressure" variable is not equal to the "BL Back Pressure" variable are picked out, since these two values must be equal according to the default of the plant control. The data loss is very small.

2. The sets of data are divided into classes in which the four setting parameters (PA, SA, TA, BL Front Pressure, see above) are constant in temporal succession,

[0092] i.e., the jth class comprises the data sets D_j..

3. Classes in which there are fewer than 30 data sets are picked out in order that transient phenomena have no great influence.

4. For each class, an arithmetic mean value $\overline{\Phi_j}$ and an empirical standard deviation s_j are determined for all the measured variables:

[0093]

$$\overline{\Phi}_j = \frac{1}{v_j} \cdot \sum_{k=1}^{v_j} \Phi_{jk} \qquad (17),$$

$$s_j = \begin{pmatrix} \left(\frac{1}{v_j - 1} \cdot \sum_{k=1}^{v_j} \left(\Phi_{jk}^{(1)} - \overline{\Phi}_j^{(1)}\right)^2\right)^{\frac{1}{2}} \\ \vdots \\ \left(\frac{1}{v_j - 1} \cdot \sum_{k=1}^{v_j} \left(\Phi_{jk}^{(m)} - \overline{\Phi}_j^{(m)}\right)^2\right)^{\frac{1}{2}} \end{pmatrix} \qquad (18).$$

5. Classes in which the mean values for the variables PA, SA, TA or BL Front Pressure are too far away from the corresponding setting parameters are picked out. Therefore, in these classes it ~~[was]~~ **is** not possible to reach the setting values.

STATISTICAL CHARACTERISTIC VARIABLES FOR THE GIVEN CLASSES AND THEIR GRAPHIC REPRESENTATION

[0094] Apart from the arithmetic mean values and the empirical standard deviations which were determined for the individual classes, a common standard deviation s is also determined according to

[0095]

$$s = \begin{pmatrix} \left(\frac{1}{v - 1} \cdot \sum_{j=1}^{u} (v_j - 1) s_j^{(1)^2}\right)^{\frac{1}{2}} \\ \vdots \\ \left(\frac{1}{v - 1} \cdot \sum_{j=1}^{u} (v_j - 1) s_j^{(m)^2}\right)^{\frac{1}{2}} \end{pmatrix} \tag{19}$$

[0096] where u stands for the number of classes (here 205) and v stands for the sum of v_j, i.e., v is the number of all the measured values used (here 38915).

LINEAR REGRESSION MODELS FOR FUNCTION APPROXIMATIONS

[0097] For each measured variable (item of measurement data) $\Phi^{(i)}$ ($i=1,2,\ldots,m$), a linear regression model is calculated on the basis of the arithmetic mean over the classes in dependence on the quadratic combination of the four setting parameters. In the following representation, $x \in \mathbf{R}^4$, where

[0098] $x^{(1)}$: Primary Air (PA)

[0099] $x^{(2)}$: Secondary Air (SA)

[00100] $x^{(3)}$: Tertiary Air (TA)

[00101] $x^{(4)}$: Black Liquor (BL) Front Pressure

[00102] applies. $u \in \mathbf{N}$ denotes the number of classes. Each measured variable $\Phi^{(i)}$ is modeled by

[00103]

$$\Phi^{(i)}(x, \omega) = a_i^T r(x) + e_i(\omega) \tag{20}$$

[00104] with $a_i \in \mathbf{R}^{15}$. Here the following applies:

[00105]

$$r : \mathbf{R}^4 \to \mathbf{R}^{15} \tag{21}$$

$$(\zeta_1, \zeta_2, \zeta_3, \zeta_4)^T \to (1, \zeta_1, \zeta_2, \zeta_3, \zeta_4, \zeta_1^2, \zeta_2^2, \zeta_3^2, \zeta_4^2, \zeta_1\zeta_2, \zeta_1\zeta_3, \zeta_1\zeta_4, \zeta_2\zeta_3, \zeta_2\zeta_4, \zeta_3\zeta_4)^T \tag{22}$$,

[00106] i.e., polynomials of the second degree are adapted to the measurement data, and

[00107]

$$e_i : \Omega \to \mathbf{R} \tag{23}$$

[00108] is a random variable with the expected value 0.

[00109] The vector a_i is determined by the method of

[00110] least squares, but the ~~[ ]~~[00111] arithmetic means

$$\left(x_j, \Phi_{j\,k}^{(i)}\right)^T$$

[00113] are used instead of the ~~[.]~~[00114] original data sets

$$\left(x_j, \overline{\Phi}_j^{(i)}\right)^T$$

.

[00116] This procedure is suitable, since linear regression models estimate in particular expected values. This results in the following minimization problem:

[00117]

$$\min_{a_i \in \mathbf{R}^{15}} \left\{ \left\| \begin{pmatrix} \overline{\Phi}_1^{(i)} \\ \vdots \\ \overline{\Phi}_u^{(i)} \end{pmatrix} - \begin{pmatrix} r(x_1)^T \\ \vdots \\ r(x_u)^T \end{pmatrix} \cdot \begin{pmatrix} a_i^{(1)} \\ \vdots \\ a_i^{(15)} \end{pmatrix} \right\|_2^2 \right\} \qquad (24).$$

[00118] Let a_i be the optimum point of the quadratic minimization ~~problem~~ problem from equation (24). Furthermore, the following applies:

[00119]

$$\hat{y}_i := \begin{pmatrix} r(x_1)^T \\ \vdots \\ r(x_u)^T \end{pmatrix} \cdot \begin{pmatrix} \bar{a}_i^{(1)} \\ \vdots \\ \bar{a}_i^{(15)} \end{pmatrix} \in \mathbf{R}^u \qquad (25),$$

$$\bar{y}_i := \frac{1}{u} \cdot \sum_{j=1}^{u} \overline{\Phi}_j^{(i)} \in \mathbf{R} \qquad (26).$$

[00120] To validate the regression theorem, a coefficient of determination R^2 is calculated according to

~~[with~~

~~]~~[00121]

$$R^2 := \frac{\sum_{j=1}^{u} \left(\hat{y}_i^{(j)} - \bar{y}_i \right)^2}{\sum_{j=1}^{u} \left(\overline{\Phi}_j^{(i)} - \bar{y}_i \right)^2} = \frac{\hat{y}_i^T \hat{y}_i - u\bar{y}_i^2}{\overline{\Phi}^{(i)T} \overline{\Phi}^{(i)} - u\bar{y}_i^2} \qquad (27)$$

[00122] with

[00123]

$$\overline{\Phi}^{(i)} = \begin{pmatrix} \overline{\Phi}_1^{(i)} \\ \vdots \\ \overline{\Phi}_u^{(i)} \end{pmatrix} \qquad (28).$$

[00124] The closer R^2_i is to 1, the better the dependent variable is represented by the independent variables $\left(0 \leq R_i^2 \leq 1\right)$ [redacted]

[00125] In addition, a maximum $E^{(i)}_{max}$ for an absolute value of the deviation of the data from the model is specified as

[00126]

$$E_{max}^{(i)} := \max_{j=1,\ldots,u} \left\{ \left| \overline{\Phi}_j^{(i)} - \hat{y}_i^{(j)} \right| \right\} \qquad (29).$$

[00127] $E^{(i)}_{90\%}$ is that value below which at least 90% of the absolute values of the deviations of the data from the model lie. By analogy with this, $E^{(i)}_{80\%}$ is that value below which at least 80% of the absolute values of the deviations of the data from the model lie. With the optimum point a_i of the minimization problem according to equation (24), a model $\tilde{\Phi}^{(i)}$ [redacted] of the expected value of the measured variable $\overline{\Phi}^{(i)}$ can be specified as

[00128]

$$\tilde{\Phi}^{(i)} := \mathbf{R}^n \rightarrow \mathbf{R} \qquad (30),$$

$$x \rightarrow \overline{a}_i^T r(x) \qquad (31).$$

[00129] In particular, the gradient $\nabla\tilde{\Phi}^{(i)}$ [redacted] can be analytically specified by

[00130]

$$\nabla\tilde{\Phi}^{(i)}(x) = \frac{dr}{dx}(x) \cdot \bar{a}_i \quad \text{for all} \quad x \in \mathbf{R}^n \tag{32}$$

[00131] The above-described method and system are illustrative of the principles of the present invention. Numerous modifications and adaptations will be readily apparent to those skilled in this art without departing from the spirit and scope of the present invention.

ABSTRACT

~~[Method and arrangement for designing a technical system To achieve the object, a method]~~**[00132]** **A method is provided** for designing a technical system in which measurement data of a predetermined system are described **based** on ~~[the basis of]~~ a substitute model ~~[is specified]~~. A numerical value for the quality of the substitute model is determined by comparing the measurement data of the predetermined system with data determined by the substitute model. On the basis of the numerical value for the quality, the substitute model is adapted to be of as high a quality as possible. The substitute model adapted with regard to its quality is used for designing the technical system.

09/857281
JC18 Rec'd PCT/PTO 01 JUN 2001

SPECIFICATION

TITLE

METHOD AND ARRANGEMENT FOR DESIGNING A TECHNICAL SYSTEM

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The invention relates to a method and arrangement for designing a technical system.

Description of the Related Art

[0002] The system behavior of a technical system, for example, a process engineering plant or system in heavy industry, depends on numerous parameters. In the course of designing such a system, particularly in the case of a new design or when adapting or adjusting an already existing system, it is necessary to comply with preconditions such as the cost-effectiveness or environmental impact of the system. Each precondition is formulated as a target function, the general aim being to optimize this with respect to the other target functions.

SUMMARY OF THE INVENTION

[0003] The object of the invention is to make it possible for a technical system to be designed on the basis of measurement data of a predetermined system. Specifically with regard to the optimization of the existing system or with regard to an optimized new design of a system, such use of known measurement data is of great significance.

[0004] This object is achieved a method and apparatus described below.

[0005] To achieve the object, the present invention provides a method for designing a technical system in which measurement data of a predetermined system are described on

the basis of a substitute model. A numerical value for the quality of the substitute model is determined by comparing the measurement data of the predetermined system with data determined by the substitute model. Based on the numerical value for the quality, the substitute model is adapted to be of as high a quality as possible.

[0006] The substitute model adapted with regard to its quality is used for designing the technical system.

[0007] The measurement data obtained from many different realized systems are used for describing the substitute model. The substitute model attempts to replicate the predetermined system as well as possible. The numerical value for the quality of the replication is determined by comparing the actual measurement data with the data obtained on the basis of the substitute model. A great difference between the measurement data and the data of the substitute model corresponds to poor quality, that is, a poor mapping of the predetermined system into the substitute model. The numerical value for the quality is used to adapt the substitute model to make the quality itself become as high as possible and consequently to make the substitute model describe the predetermined system as well as possible. The high-quality substitute model obtained in this way is used for designing the technical system.

[0008] Designing is understood in a general sense as meaning both the new design of a technical system and the adaptation of an already existing technical system.

[0009] One development comprises that the substitute model is a regression model. The regression model is based on the description

[0010] $$Y_i = f_\beta(x_i) + e_i$$

[0011] where

[0012] (y_i, x_i) denotes predetermined pairs of

values,

[0013] f_β denotes a function which is dependent on a parameter β, and

[0014] e_i denotes an error.

[0015] It is then intended to minimize the error (as a function of β):

$$\sum_{i=1}^{n} e_i^2 = \varphi(\beta).$$

[0016]

[0017] If the following example

[0018] $Y = \beta_0 + \beta_1 x + \beta_2 x^2 + e$

[0019] is taken as a basis, the functional relationship is of a quadratic order, while the regression model (function, dependent on β) is linear.

[0020] In another development, the quality can be determined on the basis of a mean square deviation of the measurement data from the data determined by the substitute model. The adaptation of the substitute model takes place by minimizing the mean square deviation.

[0021] One refinement comprises that the measurement data are sorted according to their quality, with respect to the deviation of the latter from the data determined by the substitute model, and a predetermined number of n% of the worst measurement data are picked out. Consequently, a quality is determined for each item of measurement data, the volume of measurement data, preferably in the form of a list, being sorted according to their quality and the n% of the worst measurement data, or the n worst measurement data, being picked out. In particular, it must be checked whether the n% of worst measurement data or n worst measurement data lie in a continuous range. If this is the case, these measurement data are not picked out, since they very

probably do not represent measurement errors but a continuous range which is not mapped accurately enough by the substitute model.

[0022] Another development comprises that the measurement data are subjected to a preprocessing operation. Since, in an actual predetermined system, a large amount of measurement data occur per unit of time, it is advisable to subject these measurement data to a preprocessing operation and consequently ensure that largely significant measurement data are taken for forming the substitute model. The preprocessing operation preferably finds its expression in a reduction in the number of measurement data.

[0023] In the process, the measurement data are divided into classes according to predetermined criteria. The measured values of a class are assessed and those measured values for which the assessment lies below a predetermined first threshold value are picked out. The picking out of the measured values results in a reduction with regard to the number of measured values. This results in a significantly reduced number of measured values for a further processing operation. The further processing operation can take place with less computing effort in comparison with the unreduced number of measured values.

[0024] The classes themselves can also be assessed. In particular, a class for which the assessment lies below a predetermined second threshold value can be picked out. As a result, an additional reduction of the number of measured values is obtained.

[0025] Another development of the preprocessing operation comprises that a criterion for the classification is that, for each class, measured values are determined as a default for setting parameters of the technical system. The technical system is typically set on the basis of a predetermined number of setting parameters; after setting, a reaction of the system

to the setting parameters takes place (usually with a time delay) (transient response, transient phenomenon of the system). After setting, consequently a certain set of measured values which can be assigned to the transient phenomenon are recorded, with measured values continuing to occur after the transient phenomenon has come to an end (transition to steady-state operation), and are assigned to the predetermined set of setting parameters. Adjusting the setting parameters determines a new class. All of the measured values which respectively occur after adjustment of the setting parameters belong in a class of their own.

[0026] In addition, measured values of a class which can be assigned to the respective transient phenomenon can be picked out. Furthermore, erroneous measured values can be picked out. The setting of large technical systems is in many cases directed at long-term steady-state operation. It is advisable for the measured values which relate to the transient phenomenon (of short duration in relation to the steady-state operation after the transient phenomenon has come to an end) to be picked out, since they have the effect of falsifying measured values for steady-state operation. In particular, when modeling the technical system, the measurement data of the steady-state behavior of the system are of interest.

[0027] One refinement comprises reducing the number of measured values in a class by determining at least one representative value for the measured values of the class. Such a representative value may be:

a) a mean value (for example a sliding mean value) of the measured values of the class,

b) a maximum value of the measured values of the class,

c) a minimum value of the measured values of the class,

d) a median.

[0028] In the case of variant d), one advantage is that a

value which actually exists can always be determined, whereas the mean value a) does not itself occur as a value.

[0029] Depending on the application, a suitable choice can be made for determining the representative value of a class.

[0030] An entire class with measured values may be picked out if it contains less than a predetermined number of measured values.

[0031] Another refinement comprises that those measured values which vary by more than a predetermined threshold value from a predeterminable value are picked out. The predeterminable value may be a mean value of all the measured values of the class or a measured value to be expected in response to the respective setting parameters of the technical system.

[0032] Within another development, the data obtained by way of designing are used for controlling a technical plant. In addition, the controlling of the technical plant can take place at the running time of the system (i.e., online).

[0033] Also specified for achieving the object is an arrangement for designing a technical system which has a processor unit set up such that measurement data of a predetermined system can be described on the basis of a substitute model. A numerical value for the quality of the substitute model can be determined by comparing the measurement data of the predetermined system with data determined by the substitute model. On the basis of the numerical value for the quality, the substitute model is adapted to be of as high a quality as possible. The substitute model adapted with regard to its quality is used for designing the technical system.

[0034] This arrangement is particularly suitable for carrying out the method according to the invention or one of its developments explained above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] Exemplary embodiments of the invention are presented and explained below with reference to the drawing, in which:

[0036] Figure 1 is a block diagram which contains steps of a method for designing a technical system;

[0037] Figure 2 is a schematic diagram of a recovery boiler;

[0038] Figure 3 is a chart showing the input variables of the recovery boiler;

[0039] Figure 4 is a chart showing the manipulated variables of the recovery boiler; and

[0040] Figure 5 is a chart showing the output variables of the recovery boiler.

DETAILED DESCRIPTION OF THE INVENTION

[0041] Figure 1 shows a block diagram which contains steps of a method for designing a technical system. In a step 101, a substitute model (preferably a regression model) is formed on the basis of measurement data. To adapt the substitute model created in step 101 to the measurement data (i.e., to perform a refinement of the substitute model) so that the measurement data describe the substitute model in adequate approximation, a numerical value for the quality of the substitute model is determined in a step 102. This numerical value is determined by comparing the measurement data of the predetermined system with data determined by the substitute model. Each item of measurement data preferably receives a numerical value for the quality, which numerical value characterizes the deviation of the item of measurement data from the associated value determined by the substitute model. The sum of all the numerical values for the quality for all the measurement data determines an overall quality for the substitute model. In a step 103, the quality is maximized by minimizing the numerical value for the quality (or a negative

quality for the coincidence of the substitute model with the predetermined system). Once an appropriately high quality for the substitute model has been determined, this substitute model is used for designing the technical system in a step 104. The designing may constitute both a new design (cf. step 105) or an adaptation of an already existing technical system (cf. step 106).

[0042] Figure 2 shows a schematic diagram of a recovery boiler. An exemplary embodiment of the method described above is illustrated below on the basis of the example of a "recovery boiler".

[0043] In the paper and pulp industry, various chemicals and also heat and electrical energy are required for the digestion of pulp. The recovery boiler can be used to recover the chemicals used and also thermal energy from a concentrated process liquor (black liquor). It is decisively significant to measure the recovery of the chemicals for the cost-effectiveness of the overall plant.

[0044] The black liquor is combusted in a char bed 201. As this happens, an alkali fusion is formed, flowing away via a line 202. In further process steps, the chemicals used are recovered from the constituents of the alkali fusion. Released heat of combustion is used for generating steam. The combustion of the waste liquor and consequently the recovery of the chemicals begins with the atomization of the black liquor via atomizer nozzles 204 into a combustion chamber 203. Particles of the atomized black liquor are dried as they fall through the hot flue gas. The dried liquor particles fall onto the char bed 201, with a first combustion and a chemical reduction taking place. Volatile constituents and reaction products pass into an oxidation zone, in which oxidizing reactions proceed and in which the combustion is completed.

[0045] Important targets for controlling the recovery boiler are the steam production for obtaining energy, the

maintaining of emission values from environmental aspects and the efficiency of the chemical reduction.

[0046] The combustion operation, and consequently the targets, are controlled in particular by the air supply on three levels (Primary Air (PA), Secondary Air (SA), Tertiary Air (TA)). The overall process is subject to numerous influences, which have to be taken into account in the modeling:

a) the measurement of the variables is often subject to strong fluctuations;

b) unmeasured and unmeasurable influencing variables exist;

c) any alteration of the parameters which can be set causes transient phenomena; and

d) the technical plant becomes soiled and is cleaned at predetermined intervals, resulting each time in a temporal drift in the system behavior.

[0047] The measured variables of the overall process are divided into input variables (cf. Figure 3) and output variables (cf. Figure 5). Measured values are stored every minute. Four of the input variables are at the same time also manipulated variables (also: parameters which can be set; cf. Figure 4). The manipulated variables are regarded essentially as free parameters of the overall process which can be set independently of one another. Some of the other input variables are more or less dependent on the manipulated variables. According to one target, in the case of the recovery boiler, the "BL Front Pressure" and "BL Back Pressure" variables are always controlled such that they are the same. The four manipulated variables (cf. Figure 4) are preferably stored as manipulated variables (with the desired, preset value) and as input variables (with the measured, actual value).

[0048] In the case of the recovery boiler, one problem is that of meeting targets which: 1) are determined in dependence on the parameters to be set, and 2) are defined by measured variables. A three-stage procedure is chosen here to solve the problem:

1. The targets to be considered are modeled by stochastic methods, these models being updated by new measurements (data-driven, empirical modeling). For this step it is advisable to use not just a single model but instead global models for the identification of areas of interest in a parameter space determined by the targets and local models for the exact calculation of optimum operating points. The models used are assessed by measures of quality.

2. If the models considered are not sufficiently accurate (measure of quality) due to the data situation, new operating points are evaluated on a specific basis to improve the model (experimental design). Furthermore, by the use of global stochastic optimizing methods with respect to the targets, attractive areas are identified in dependence on the current global model.

3. For the local optimization, local models are devised and, if appropriate, the available sets of data are extended on a specific basis (experimental design).

[0049] The targets constitute physical-technical or business-management criteria, which generally have to conform to boundary conditions and/or safety conditions. Often a number of these criteria have to be considered simultaneously. The use of a stochastic model can be used in particular to simulate in the computer the target variables to be optimized and their dependence on the parameters to be set. This is necessary whenever measurements are very cost-intensive or very time-consuming. In the case of safety requirements, possible hazardous situations can be avoided.

[0050] In the case of the recovery boiler, an online

optimization which is based on a number of data is necessary because the physical-chemical processes cannot be quantitatively modeled with sufficient accuracy and because the behavior of the plant is subject to fluctuations in the course of operation. Knowledge of this behavior must be continually extended by selective choice of new operating points. Therefore, the already described three-stage procedure of stochastic modeling and mathematical optimization is recommendable as part of online optimization.

DESCRIPTION OF THE INPUT VARIABLES

[0051] The a input variables ($a \in$ **N**, **N**: set of natural numbers) are generally dependent on n actuated variables $n \in$ **N** and on random effects. They can be described as follows:

[0052] Let $(\Omega, S, \mathbf{P})$ be a probability space and $\mathbf{B}^v$ be a Borel σ algebra over □^{v} (□: set of real numbers) for each $v \in$ **N**. The input variables are represented by a $\mathbf{B}^n \times S - \mathbf{B}^a$-measurable mapping φ:

$$\varphi : \mathbf{R}^n \times \Omega \to \mathbf{R}^a \qquad (1).$$

[0053] The domain of the mapping φ is a Cartesian product of two sets. If the respective projections onto the individual sets are considered, the following mappings are obtained:

[0054] $$\varphi_x : \Omega \to \mathbf{R}^a,\ \omega \to \varphi(x, \omega) \quad \text{for all} \quad x \in \mathbf{R}^n \qquad (2),$$

[0055] $$\varphi^\omega : \mathbf{R}^n \to \mathbf{R}^a,\ x \to \varphi(x, \omega) \quad \text{for all} \quad \omega \in \Omega \qquad (3).$$

[0056] $\{\varphi_x;\ x \in$ ℝ [0057] is a stochastic process with an index set

[0058] □^{n}, and a mapping φ^ω is, for each event $\omega \in \Omega$, a path of this stochastic process.

[0059] In the case of the recovery boiler, $n=4$ and $a=14$ (after elimination of the "BL Back Pressure" variable).

[0060] On account of the required measurability of the mapping φ_x, for each $x \in \mathbb{R}^n$ the mapping φ_x is a random variable. Under suitable additional preconditions, expectation values and higher moments can be considered. This approach permits the step from stochastic models to deterministic optimization problems. In the case of a deterministic optimization problem, the target function can be set directly by a variable, whereas the stochastic variable influences the target function but does not permit a specific setting.

DESCRIPTION OF THE OUTPUT VARIABLES

[0061] The process model M of the recovery boiler is described as a function in dependence on the input variables and further random effects. In this case let $(\mathbf{\Omega}, \mathbf{S}, \mathbf{P})$ be the above probability space. The process model M is then a $\mathbf{B}^a \times \mathbf{S} - \mathbf{B}^b$-measurable mapping:

[0062]
$$M : \mathbf{R}^a \times \Omega \rightarrow \mathbf{R}^b \qquad (4),$$

[0063] where b denotes the number of output variables.

[0064] Since the recovery boiler is subject to a cyclical temporal drift (from cleaning phase to cleaning phase), a description with a time parameter is also conceivable. The output variables can be represented by $\mathbf{B}^n \times \mathbf{S} - \mathbf{B}^b$-measurable mappings ψ:

$$\psi : \mathbf{R}^n \times \Omega \rightarrow \mathbf{R}^b \qquad (5),$$

[0065]
$$(x, \omega) \rightarrow M(\varphi(x, \omega), \omega) \qquad (6).$$

[0066] If the respective projections onto the individual sets of the domain are considered, the following mappings are

obtained

$$\psi_x: \Omega \to \mathbf{R}^b,\ \omega \to \psi(x, \omega) \quad \text{for all} \quad x \in \mathbf{R}^n \tag{7}$$

$$\psi^{\omega}: \mathbf{R}^n \to \mathbf{R}^b,\ x \to \psi(x, \omega) \quad \text{for all} \quad \omega \in \Omega \tag{8}$$

[0067]

[0068] $\{\psi_x;\ x \in$

[0069] is a stochastic process with an index set

[0070] $\mathbb{R}^n$, and the mapping ψ^{ω} is, for each $\omega \in \mathbf{\Omega}$, a path of this stochastic process.

[0071] In the case of the recovery boiler, b=15.

[0072] The fact that in the definition of ψ a distinction is not drawn between the events ω used does not mean that there is any restriction, since $\mathbf{\Omega}$ can be represented as a Cartesian product of an $\mathbf{\Omega}_1$ and an $\mathbf{\Omega}_2$. The above representation consequently also comprises the model:

$$\psi : \mathbf{R}^n \times \Omega_1 \times \Omega_2 \to \mathbf{R}^b \tag{9}$$

$$(x, \omega_1, \omega_2) \to M(\varphi(x, \omega_1), \omega_2) \tag{10}$$

[0073]

DESCRIPTION OF THE AVAILABLE SETS OF DATA

[0074] With the descriptions in the two foregoing sections, the input variables and the output variables can be combined together to form measured variables (= measurement data) $\mathbf{\Phi}$. $\mathbf{\Phi}$ is a $\mathcal{B}^n \times \mathcal{S}$ - $\mathcal{B}^m$-measurable mapping with m = a + b and

$$\Phi : \mathbf{R}^n \times \Omega \to \mathbf{R}^m \tag{11}$$

$$(x, \omega) \to \begin{pmatrix} \varphi(x, \omega) \\ \psi(x, \omega) \end{pmatrix} \tag{12}$$

[0075]

[0076] If the respective projections onto the individual

sets of the domain are again considered, the following mappings are obtained:

$$\Phi_x: \Omega \rightarrow \mathbf{R}^m,\ \omega \rightarrow \Phi(x, \omega) \quad \text{for all} \quad x \in \mathbf{R}^n \qquad (13),$$

$$\Phi^\omega: \mathbf{R}^n \rightarrow \mathbf{R}^m,\ x \rightarrow \Phi(x, \omega) \quad \text{for all} \quad \omega \in \Omega \qquad (14).$$

[0077] $\{\Phi_x;\ x \in$ [0078] is a stochastic process with an index set

[0079] $\mathbb{R}^n$, and the mapping Φ^ω is, for each $\omega \in \Omega$, a path of this stochastic process.

[0080] For each chosen related variable tupel x, in the case of the recovery boiler many realizations of Φ_x are determined and stored, i.e., for each $x_j \in \mathbb{R}^n$ numerous realizations

$$\Phi_{jk} := \Phi(x_j, \omega_{jk}) \qquad (15)$$

$$\text{with} \quad \omega_{jk} \in \Omega;\ k = 1,2,\ldots, v_j;$$

[0081] $$v_j \in \mathbf{N};\ j = 1,2,\ldots, u;\ u \in \mathbf{N}$$

[0082] are considered. The stored sets of data D_{jk} of the recovery boiler are consequently (n+m) tupels:

[0083] $$D_{jk} = \begin{pmatrix} x_j \\ \Phi_{jk} \end{pmatrix}, \quad k = 1,2,\ldots, v_j;\ j = 1,2,\ldots, u \qquad (16).$$

[0084] In this case, D_{j1k1} is stored before D_{j2k2} if

[0085] $$(j_1 < j_2) \vee ((j_1 = j_2) \wedge (k_1 < k_2))$$

[0086] applies.

DATA COMPRESSION BY CLASSIFICATION OF THE PARAMETERS

[0087] Since for each manipulated variable tupel x there

are generally a number of realizations of Φ_x, a classification of the parameters by forming arithmetic mean values is a suitable operation as a first step of the statistical data analysis on account of the complex stochastic properties of the process to be considered. Moreover, sets of data which are obviously erroneous are picked out. A set of data which is obviously erroneous is, for example, a physically impossible measurement which cannot occur in reality, particularly due to a setting made.

[0088] Procedure:

1. Sets of data in which the "BL Front Pressure" variable is not equal to the "BL Back Pressure" variable are picked out, since these two values must be equal according to the default of the plant control. The data loss is very small.
2. The sets of data are divided into classes in which the four setting parameters (PA, SA, TA, BL Front Pressure, see above) are constant in temporal succession,

[0089] i.e., the jth class comprises the data sets $D_{j\bullet}$.

3. Classes in which there are fewer than 30 data sets are picked out in order that transient phenomena have no great influence.
4. For each class, an arithmetic mean value $\overline{\Phi_j}$ and an empirical standard deviation s_j are determined for all the measured variables:

$$\overline{\Phi}_j = \frac{1}{v_j} \cdot \sum_{k=1}^{v_j} \Phi_{jk} \qquad (17),$$

$$s_j = \begin{pmatrix} \left(\frac{1}{v_j - 1} \cdot \sum_{k=1}^{v_j} \left(\Phi_{jk}^{(1)} - \overline{\Phi}_j^{(1)}\right)^2\right)^{\frac{1}{2}} \\ \vdots \\ \left(\frac{1}{v_j - 1} \cdot \sum_{k=1}^{v_j} \left(\Phi_{jk}^{(m)} - \overline{\Phi}_j^{(m)}\right)^2\right)^{\frac{1}{2}} \end{pmatrix} \qquad (18).$$

[0090]

5. Classes in which the mean values for the variables PA, SA, TA or BL Front Pressure are too far away from the corresponding setting parameters are picked out. Therefore, in these classes it is not possible to reach the setting values.

STATISTICAL CHARACTERISTIC VARIABLES FOR THE GIVEN CLASSES AND THEIR GRAPHIC REPRESENTATION

[0091] Apart from the arithmetic mean values and the empirical standard deviations which were determined for the individual classes, a common standard deviation s is also determined according to

$$s = \begin{pmatrix} \left(\frac{1}{v - 1} \cdot \sum_{j=1}^{u} \left(v_j - 1\right) s_j^{(1)2}\right)^{\frac{1}{2}} \\ \vdots \\ \left(\frac{1}{v - 1} \cdot \sum_{j=1}^{u} \left(v_j - 1\right) s_j^{(m)2}\right)^{\frac{1}{2}} \end{pmatrix} \qquad (19)$$

[0092]

[0093] where u stands for the number of classes (here 205) and v stands for the sum of v_j, i.e., v is the number of all the measured values used (here 38915).

LINEAR REGRESSION MODELS FOR FUNCTION APPROXIMATIONS

[0094] For each measured variable (item of measurement data) $\Phi^{(i)}$ $(i=1,2,\ldots,m)$, a linear regression model is calculated on the basis of the arithmetic mean over the classes in dependence on the quadratic combination of the four setting parameters. In the following representation, $x \in \mathbf{R}^4$, where

[0095] $x^{(1)}$: Primary Air (PA)

[0096] $x^{(2)}$: Secondary Air (SA)

[0097] $x^{(3)}$: Tertiary Air (TA)

[0098] $x^{(4)}$: Black Liquor (BL) Front Pressure

[0099] applies. $u \in \mathbf{N}$ denotes the number of classes. Each measured variable $\Phi^{(i)}$ is modeled by

[00100]

$$\Phi^{(i)}(x, \omega) = a_i^T r(x) + e_i(\omega) \tag{20}$$

[00101] with $a_i \in \mathbf{R}^{15}$. Here the following applies:

$$r : \mathbf{R}^4 \to \mathbf{R}^{15} \tag{21}$$

[00102]

$$(\zeta_1, \zeta_2, \zeta_3, \zeta_4)^T \to (1, \zeta_1, \zeta_2, \zeta_3, \zeta_4, \zeta_1^2, \zeta_2^2, \zeta_3^2, \zeta_4^2, \zeta_1\zeta_2, \zeta_1\zeta_3, \zeta_1\zeta_4, \zeta_2\zeta_3, \zeta_2\zeta_4, \zeta_3\zeta_4)^T \tag{22}$$,

[00103] i.e., polynomials of the second degree are adapted to the measurement data, and

[00104]

$$e_i : \Omega \to \mathbf{R} \tag{23}$$

[00105] is a random variable with the expected value 0.

[00106] The vector a_i is determined by the method of

[00107] least squares, but the arithmetic means

[00108] $\left(x_j, \Phi_j^{(i}\right.$

[00109] are used instead of the original data sets

[00110] $\left(x_j, \overline{\Phi}_j^{(i)}\right)$

[00111] This procedure is suitable, since linear regression models estimate in particular expected values. This results in the following minimization problem:

[00112]
$$\min_{a_i \in \mathbf{R}^{15}} \left\{ \left\| \begin{pmatrix} \overline{\Phi}_1^{(i)} \\ \vdots \\ \overline{\Phi}_u^{(i)} \end{pmatrix} - \begin{pmatrix} r(x_1)^T \\ \vdots \\ r(x_u)^T \end{pmatrix} \cdot \begin{pmatrix} a_i^{(1)} \\ \vdots \\ a_i^{(15)} \end{pmatrix} \right\|_2^2 \right\} \quad (24).$$

[00113] Let $\overline{a_i}$ be the optimum point of the quadratic minimization problem from equation (24). Furthermore, the following applies:

$$\hat{y}_i := \begin{pmatrix} r(x_1)^T \\ \vdots \\ r(x_u)^T \end{pmatrix} \cdot \begin{pmatrix} \overline{a}_i^{(1)} \\ \vdots \\ \overline{a}_i^{(15)} \end{pmatrix} \in \mathbf{R}^u \quad (25),$$

[00114]
$$\overline{y}_i := \frac{1}{u} \cdot \sum_{j=1}^{u} \overline{\Phi}_j^{(i)} \in \mathbf{R} \quad (26).$$

[00115] To validate the regression theorem, a coefficient of determination R^2 is calculated according to

[00116]
$$R^2 := \frac{\sum_{j=1}^{u} \left(\hat{y}_i^{(j)} - \overline{y}_i\right)^2}{\sum_{j=1}^{u} \left(\overline{\Phi}_j^{(i)} - \overline{y}_i\right)^2} = \frac{\hat{y}_i^T \hat{y}_i - u\overline{y}_i^2}{\overline{\Phi}^{(i)T}\overline{\Phi}^{(i)} - u\overline{y}_i^2} \quad (27)$$

[00117] with

[00118]
$$\overline{\Phi}^{(i)} = \begin{pmatrix} \overline{\Phi}_1^{(i)} \\ \vdots \\ \overline{\Phi}_u^{(i)} \end{pmatrix} \quad (28).$$

[00119] The closer R^2_i is to 1, the better the dependent variable is represented by the independent variables $\left(0 \le R_i^2 \le 1\right)$.

[00120] In addition, a maximum $E^{(i)}_{max}$ for an absolute value of the deviation of the data from the model is specified as

$$E_{max}^{(i)} := \max_{j=1,\dots,u} \left\{\left|\overline{\Phi}_j^{(i)} - \hat{y}_i^{(j)}\right|\right\} \quad (29).$$

[00121]

[00122] $E^{(i)}_{90\%}$ is that value below which at least 90% of the absolute values of the deviations of the data from the model lie. By analogy with this, $E^{(i)}_{80\%}$ is that value below which at least 80% of the absolute values of the deviations of the data from the model lie. With the optimum point a_i of the minimization problem according to equation (24), a model $\tilde{\Phi}^{(i)}$ of the expected value of the measured variable $\overline{\Phi}^{(i)}$ can be specified as

$$\tilde{\Phi}^{(i)} := \mathbf{R}^n \to \mathbf{R} \quad (30),$$

$$x \to \overline{a}_i^T r(x) \quad (31).$$

[00123]

[00124] In particular, the gradient $\nabla\tilde{\Phi}^{(i)}$ can be analytically specified by

$$\nabla\tilde{\Phi}^{(i)}(x) = \frac{dr}{dx}(x) \cdot \overline{a}_i \quad \text{for all} \quad x \in \mathbf{R}^n \quad (32).$$

[00125]

[00126] The above-described method and system are illustrative of the principles of the present invention. Numerous modifications and adaptations will be readily apparent to those skilled in this art without departing from the spirit and scope of the present invention.

ABSTRACT

[00127] A method is provided for designing a technical system in which measurement data of a predetermined system are described based on a substitute model. A numerical value for the quality of the substitute model is determined by comparing the measurement data of the predetermined system with data determined by the substitute model. On the basis of the numerical value for the quality, the substitute model is adapted to be of as high a quality as possible. The substitute model adapted with regard to its quality is used for designing the technical system.

3|PRTS

09/857281
JC18 Rec'd PCT/PTO 01 JUN 2001

Description

Method and arrangement for designing a technical system

The invention relates to a method and arrangement for designing a technical system.

The system behavior of a technical system, for example a process engineering plant or system in heavy industry, depends on numerous parameters. In the course of designing such a system, that is in particular in the case of a new design or when adapting or adjusting an already existing system, it is necessary to comply with preconditions, for example with regard to the cost-effectiveness or environmental impact of the system. Each precondition is formulated as a target function, the optimization of which with regard to the other target functions is the general aim.

The **object** of the invention is to make it possible for a technical system to be designed on the basis of measurement data of a predetermined system. Specifically with regard to the optimization of the existing system or with regard to an optimized new design of a system, such use of known measurement data is of great significance.

This object is achieved according to the features of the independent patent claims. Developments of the invention also emerge from the dependent claims.

To achieve the object, a method for designing a technical system in which measurement data of a predetermined system are described on the basis of a substitute model is specified. A numerical value for the quality of the substitute model is determined by comparing the measurement data of the predetermined system with data determined by the substitute model. On the basis of the numerical value for the quality, the substitute model is adapted to be of as high a quality as possible.

The substitute model adapted with regard to its quality is used for designing the technical system.

The measurement data obtained from many different realized systems are used for describing the substitute model. With the substitute model it is attempted to replicate the predetermined system as well as possible. The numerical value for the quality of the replication is determined by comparing the actual measurement data with the data obtained on the basis of the substitute model. A great difference between the measurement data and the data of the substitute model corresponds to poor quality, that is poor mapping of the predetermined system into the substitute model. The numerical value for the quality is used to adapt the substitute model to make the quality itself become as high as possible and consequently to make the substitute model describe the predetermined system as well as possible. The high-quality substitute model obtained in this way is used for designing the technical system.

Designing is understood in a general sense as meaning both the new design of a technical system and the adaptation of an already existing technical system.

One development comprises that the substitute model is a regression model. The regression model is based on the description

$$Y_i = f_\beta(x_i) + e_i$$

where

(y_i, x_i) denotes predetermined pairs of values,

f_β denotes a function which is dependent on a parameter β, and

e_i denotes an error.

It is then intended to minimize the error (as a function of β):

$$\sum_{i=1}^{n} e_i^2 = \varphi(\beta).$$

If the following example

$$Y = \beta_0 + \beta_1 x + \beta_2 x^2 + e$$

is taken as a basis, the functional relationship is of a quadratic order, while the regression model (function, dependent on β) is linear.

In another development, the quality can be determined on the basis of a mean square deviation of the measurement data from the data determined by the substitute model. The adaptation of the substitute model takes place by minimizing the mean square deviation.

One refinement comprises that the measurement data are sorted according to their quality, with respect to the deviation of the latter from the data determined by the substitute model, and a predetermined number of n% of the worst measurement data are picked out. Consequently, a quality is determined for each item of measurement data, the volume of measurement data, preferably in the form of a list, being sorted according to their quality and the n% of the worst measurement data, or the n worst measurement data, being picked out. In particular, it must be checked whether the n% of worst measurement data or n worst measurement data lie in a continuous range. If this is the case, these measurement data are not picked out, since they very probably do not represent measurement errors but a continuous range which is not mapped accurately enough by the substitute model.

Another development comrises that the measurement data are subjected to a preprocessing operation. Since, in an actual predetermined system, a large amount of measurement data occur per

unit of time, it is advisable to subject these measurement data to a preprocessing operation and consequently ensure that largely significant measurement data are taken for forming the substitute model. The preprocessing operation preferably finds its expression in a reduction in the number of measurement data.

In the process, the measurement data are divided into classes according to predetermined criteria. The measured values of a class are assessed and those measured values for which the assessment lies below a predetermined first threshold value are picked out. The picking out of the measured values results in a reduction with regard to the number of measured values. This results in a significantly reduced number of measured values for a further processing operation. The further processing operation can take place with less computing effort in comparison with the unreduced number of measured values.

The classes themselves can also be assessed. In particular, a class for which the assessment lies below a predetermined second threshold value can be picked out. As a result, an additional reduction of the number of measured values is obtained.

Another development of the preprocessing operation comprises that a criterion for the classification is that, for each class, measured values are determined as a default for setting parameters of the technical system. The technical system is typically set on the basis of a predetermined number of setting parameters; after setting, a reaction of the system to the setting parameters takes place (usually with a time delay) (transient response, transient phenomenon of the system). After setting, consequently a certain set of measured values which can be assigned to the transient phenomenon are recorded, with measured values continuing to occur after the transient phenomenon has come to an end (transition to steady-state operation), and

are assigned to the predetermined set of setting parameters. By adjusting the setting parameters, a new class is determined. All the measured values which respectively occur after adjustment of the setting parameters belong in a class of their own.

In addition, measured values of a class which can be assigned to the respective transient phenomenon can be picked out. Furthermore, erroneous measured values can be picked out. The setting of large technical systems is in many cases directed at long-term steady-state operation. It is advisable for the measured values which relate to the transient phenomenon (of short duration in relation to the steady-state operation after the transient phenomenon has come to an end) to be picked out, since they have the effect of falsifying measured values for steady-state operation. In particular when modeling the technical system, the measurement data of the steady-state behavior of the system are of interest.

One refinement comprises reducing the number of measured values in a class by determining at least one representative value for the measured values of the class. Such a representative value may be:

a) a mean value (for example a sliding mean value) of the measured values of the class,

b) a maximum value of the measured values of the class,

c) a minimum value of the measured values of the class,

d) a median.

In the case of variant d), one advantage is that a value which actually exists can always be determined, whereas the mean value a) does not itself occur as a value.

Depending on the application, a suitable choice can be made for determining the representative value of a class.

An entire class with measured values may be picked out if it contains less than a predetermined number of measured values.

Another refinement comprises that those measured values which vary by more than a predetermined threshold value from a predeterminable value are picked out. The predeterminable value may be a mean value of all the measured values of the class or a measured value to be expected in response to the respective setting parameters of the technical system.

Within another development, the data obtained by means of designing are used for controlling a technical plant. In addition, the controlling of the technical plant can take place at the running time of the system, that is online.

Also specified for achieving the object is an arrangement for designing a technical system which has a processor unit, which processor unit is set up in such a way that measurement data of a predetermined system can be described on the basis of a substitute model. A numerical value for the quality of the substitute model can be determined by comparing the measurement data of the predetermined system with data determined by the substitute model. On the basis of the numerical value for the quality, the substitute model is adapted to be of as high a quality as possible. The substitute model adapted with regard to its quality is used for designing the technical system.

This arrangement is particularly suitable for carrying out the method according to the invention or one of its developments explained above.

Exemplary embodiments of the invention are presented and explained below with reference to the drawing,

in which:

figure 1 shows a block diagram which contains steps of a method for designing a technical system;

figure 2 shows a schematic diagram of a recovery boiler;

figures 3-5 show input variables, manipulated variables and output variables of the recovery boiler.

Represented in **figure 1** is a block diagram which contains steps of a method for designing a technical system. In a step 101, a substitute model is formed on the basis of measurement data. This substitute model is preferably a regression model. To adapt the substitute model created in step 101 to the measurement data, that is to perform a refinement of the substitute model, so that the measurement data describe the substitute model in adequate approximation, a numerical value for the quality of the substitute model is determined in a step 102. This numerical value is determined by comparing the measurement data of the predetermined system with data determined by the substitute model. Each item of measurement data preferably receives a numerical value for the quality, which numerical value characterizes the deviation of the item of measurement data from the associated value determined by the substitute model. The sum of all the numerical values for the quality for all the measurement data determines an overall quality for the substitute model. In a step 103, the quality is maximized by minimizing the numerical value for the quality (or a negative quality for the coincidence of the substitute model with the predetermined system). Once an appropriately high quality for the substitute model has been determined, this substitute model is used for designing the technical system in a step 104. The designing may constitute both a new design (cf. step 105) or an adaptation of an already existing technical system (cf. step 106).

Figure 2 shows a schematic diagram of a recovery boiler. An exemplary embodiment of the method described above is illustrated below on the basis of the example of a "recovery boiler".

In the paper and pulp industry, various chemicals and also heat and electrical energy are required for the digestion of pulp. The recovery boiler can be used to recover the chemicals used and also thermal energy from a concentrated process liquor (black liquor). A measure of the recovery of the chemicals is of decisive significance for the cost-effectiveness of the overall plant.

The black liquor is combusted in a char bed 201. As this happens, an alkali fusion is formed, flowing away via a line 202. In further process steps, the chemicals used are recovered from the constituents of the alkali fusion. Released heat of combustion is used for generating steam. The combustion of the waste liquor and consequently the recovery of the chemicals begins with the atomization of the black liquor via atomizer nozzles 204 into a combustion chamber 203. Particles of the atomized black liquor are dried as they fall through the hot flue gas. The dried liquor particles fall onto the char bed 201, with a first combustion and a chemical reduction taking place. Volatile constituents and reaction products pass into an oxidation zone, in which oxidizing reactions proceed and in which the combustion is completed.

Important targets for the controlling of the recovery boiler are the steam production for obtaining energy, the maintaining of emission values from environmental aspects and the efficiency of the chemical reduction.

The combustion operation, and consequently the targets, are controlled in particular by the air supply on three levels (Primary Air (PA), Secondary Air (SA), Tertiary Air (TA)). The overall process is subject to numerous influences, which have to be taken into account in the modeling:

a) the measurement of the variables is often subject to strong fluctuations;
b) unmeasured and unmeasurable influencing variables exist;
c) any alteration of the parameters which can be set causes transient phenomena;
d) the technical plant becomes soiled and is cleaned at predetermined intervals, having the result each time of a temporal drift in the system behavior.

The measured variables of the overall process are divided into input variables (cf. **figure 3**) and output variables (cf. **figure 5**). Measured values are stored every minute. Four of the input variables are at the same time also manipulated variables (also: parameters which can be set; cf. **figure 4**). The manipulated variables are to be regarded essentially as free parameters of the overall process which can be set independently of one another. Some of the other input variables are more or less dependent on the manipulated variables. According to one target, in the case of the recovery boiler the "BL Front Pressure" and "BL Back Pressure" variables are always to be controlled such that they are the same. The four manipulated variables (cf. figure 4) are preferably to be stored as manipulated variables (with the desired, preset value) and as input variables (with the measured, actual value).

In the case of the recovery boiler, one problem is that of meeting targets which are determined in dependence on the parameters to be set and

are defined by means of measured variables. A three-stage procedure is chosen here to solve the problem:

1. The targets to be considered are modeled by stochastic methods, these models being updated by new measurements (data-driven, empirical modeling). For this it is advisable to use not just a single model but instead global models for the identification of areas of interest in a parameter space determined by the targets and local models for the exact calculation of optimum operating points. The models used are assessed by measures of quality.

2. If the models considered are not sufficiently accurate (measure of quality) on account of the data situation, new operating points are evaluated on a specific basis to improve the model (experimental design). Furthermore, by the use of global stochastic optimizing methods with respect to the targets, attractive areas are identified in dependence on the current global model.

3. For the local optimization, local models are devised and, if appropriate, the available sets of data are extended on a specific basis (experimental design).

The targets constitute physical-technical or business-management criteria, which generally have to conform to boundary conditions and/or safety conditions. Often a number of these criteria have to be considered simultaneously. The use of a stochastic model can be used in particular to simulate in the computer the target variables to be optimized and their dependence on the parameters to be set. This is necessary whenever measurements are very cost-intensive

or very time-consuming. In the case of safety requirements, possible hazardous situations can be avoided.

In the case of the recovery boiler, an online optimization which is based on a number of data is necessary because the physical-chemical processes cannot be quantitatively modeled with sufficient accuracy and because the behavior of the plant is subject to fluctuations in the course of operation. Knowledge of this behavior must be continually extended by selective choice of new operating points. Therefore, the already described three-stage procedure of stochastic modeling and mathematical optimization is recommendable as part of online optimization.

DESCRIPTION OF THE INPUT VARIABLES

The a input variables ($a \in \mathbf{N}$, $\mathbf{N}$: set of natural numbers) are generally dependent on n actuated variables $n \in \mathbf{N}$ and on random effects. They can be described as follows:

Let $(\Omega, S, \mathbf{P})$ be a probability space and $\mathbf{B}^v$ be a Borel σ algebra over $\mathbb{R}^v$ ($\mathbb{R}$: set of real numbers) for each $v \in \mathbf{N}$. The input variables are represented by means of a $\mathbf{B}^n \times S - \mathbf{B}^a$-measurable mapping φ:

$$\varphi : \mathbb{R}^n \times \Omega \to \mathbb{R}^a \qquad (1).$$

The domain of the mapping φ is a Cartesian product of two sets. If the respective projections onto the individual sets are considered, the following mappings are obtained:

$$\varphi_x : \Omega \to \mathbb{R}^a,\ \omega \to \varphi(x, \omega) \quad \text{for all} \quad x \in \mathbb{R}^n \qquad (2),$$

$$\varphi^{\omega}: \mathbb{R}^n \rightarrow \mathbb{R}^a,\ x \rightarrow \varphi(x, \omega) \quad \text{for all} \quad \omega \in \Omega \qquad (3).$$

$\{\varphi_x;\ x \in \mathbb{R}^n\}$ is a stochastic process with an index set $\mathbb{R}^n$, and a mapping φ^{ω} is, for each event $\omega \in \Omega$, a path of this stochastic process.

In the case of the recovery boiler, n=4 and a=14 (after elimination of the "BL Back Pressure" variable).

On account of the required measurability of the mapping φ_x, for each $x \in \mathbb{R}^n$ the mapping φ_x is a random variable. Under suitable additional preconditions, expectation values and higher moments can be considered. This approach permits the step from stochastic models to deterministic optimization problems. In the case of a deterministic optimization problem, the target function can be set directly by means of a variable, whereas the stochastic variable influences the target function but does not permit a specific setting.

DESCRIPTION OF THE OUTPUT VARIABLES

The process model M of the recovery boiler is described as a function in dependence on the input variables and further random effects. In this case let (Ω, S, P) be the above probability space. The process model M is then a $\mathbf{B}^a \times S$ - $\mathbf{B}^b$-measurable mapping:

$$M : \mathbb{R}^a \times \Omega \rightarrow \mathbb{R}^b \qquad (4),$$

where b denotes the number of output variables.

Since the recovery boiler is subject to a cyclical temporal drift (from cleaning phase to cleaning phase), a description with a time parameter is also conceivable. The

output variables can be represented by $\mathcal{B}^n \times \mathcal{S} - \mathcal{B}^b$-measurable mappings ψ:

$$\psi : \mathbf{R}^n \times \Omega \rightarrow \mathbf{R}^b \qquad (5),$$

$$(x, \omega) \rightarrow M(\varphi(x, \omega), \omega) \qquad (6).$$

If the respective projections onto the individual sets of the domain are considered, the following mappings are obtained

$$\psi_x : \Omega \rightarrow \mathbf{R}^b,\ \omega \rightarrow \psi(x, \omega) \quad \text{for all} \quad x \in \mathbf{R}^n \qquad (7),$$

$$\psi^\omega : \mathbf{R}^n \rightarrow \mathbf{R}^b,\ x \rightarrow \psi(x, \omega) \quad \text{for all} \quad \omega \in \Omega \qquad (8).$$

$\{\psi_x;\ x \in \mathbf{R}^n\}$ is a stochastic process with an index set $\mathbf{R}^n$, and the mapping ψ^ω is, for each $\omega \in \Omega$, a path of this stochastic process.

In the case of the recovery boiler, b=15.

The fact that in the definition of ψ a distinction is not drawn between the events ω used does not mean that there is any restriction, since Ω can be represented as a Cartesian product of an Ω_1 and an Ω_2. The above representation consequently also comprises the model:

$$\psi : \mathbf{R}^n \times \Omega_1 \times \Omega_2 \rightarrow \mathbf{R}^b \qquad (9),$$

$$(x, \omega_1, \omega_2) \rightarrow M(\varphi(x, \omega_1), \omega_2) \qquad (10).$$

DESCRIPTION OF THE AVAILABLE SETS OF DATA

With the descriptions in the two foregoing sections, the input variables and the output variables can be combined together to form measured variables (= measurement data) Φ. Φ is a $\mathcal{B}^n \times \mathcal{S} - \mathcal{B}^m$-measurable mapping with m = a + b and

$$\Phi : \mathbf{R}^n \times \Omega \to \mathbf{R}^m \qquad (11),$$

$$(x, \omega) \to \begin{pmatrix} \varphi(x, \omega) \\ \psi(x, \omega) \end{pmatrix} \qquad (12).$$

If the respective projections onto the individual sets of the domain are again considered, the following mappings are obtained:

$$\Phi_x : \Omega \to \mathbf{R}^m,\ \omega \to \Phi(x, \omega) \quad \text{for all} \quad x \in \mathbf{R}^n \qquad (13),$$

$$\Phi^\omega : \mathbf{R}^n \to \mathbf{R}^m,\ x \to \Phi(x, \omega) \quad \text{for all} \quad \omega \in \Omega \qquad (14).$$

$\{\Phi_x;\ x \in \mathbf{R}^n\}$ is a stochastic process with an index set R^n, and the mapping Φ^ω is, for each $\omega \in \Omega$, a path of this stochastic process.

For each chosen related variable tupel x, in the case of the recovery boiler many realizations of Φ_x are determined and stored, i.e. for each $x_j \in R^n$ numerous realizations

$$\Phi_{jk} := \Phi(x_j, \omega_{jk}) \qquad (15)$$

with $\omega_{jk} \in \Omega;\ k = 1,2,\ldots, v_j;$

$v_j \in \mathbf{N};\ j = 1,2,\ldots,u;\ u \in \mathbf{N}$

are considered. The stored sets of data D_{jk} of the recovery boiler are consequently (n+m) tupels:

$$D_{jk} = \begin{pmatrix} x_j \\ \Phi_{jk} \end{pmatrix}, \quad k = 1,2,\ldots,v_j;\; j = 1,2,\ldots,u \qquad (16).$$

In this case, D_{j1k1} is stored before D_{j2k2} if

$$(j_1 < j_2) \vee ((j_1 = j_2) \wedge (k_1 < k_2))$$

applies.

DATA COMPRESSION BY CLASSIFICATION OF THE PARAMETERS

Since for each manipulated variable tupel x there are generally a number of realizations of Φ_x, a classification of the parameters by forming arithmetic mean values is a suitable operation as a first step of the statistical data analysis on account of the complex stochastic properties of the process to be considered. Moreover, sets of data which are obviously erroneous are picked out. A set of data which is obviously erroneous is, for example, a physically impossible measurement which cannot occur in reality, in particular on account of a setting made.

Procedure:

1. Sets of data in which the "BL Front Pressure" variable is not equal to the "BL Back Pressure" variable are picked out, since these two values must be equal according to the default of the plant control. The data loss is very small.

2. The sets of data are divided into classes in which the four setting parameters (PA, SA, TA, BL Front Pressure, see above) are constant in temporal succession,

i.e. the jth class comprises the data sets $D_{j\bullet}$.

3. Classes in which there are fewer than 30 data sets are picked out in order that transient phenomena have no great influence.

4. For each class, an arithmetic mean value $\overline{\Phi}_j$ and an empirical standard deviation s_j are determined for all the measured variables:

$$\overline{\Phi}_j = \frac{1}{v_j} \cdot \sum_{k=1}^{v_j} \Phi_{jk} \qquad (17),$$

$$s_j = \begin{pmatrix} \left(\frac{1}{v_j - 1} \cdot \sum_{k=1}^{v_j} \left(\Phi_{jk}^{(1)} - \overline{\Phi}_j^{(1)}\right)^2\right)^{\frac{1}{2}} \\ \vdots \\ \left(\frac{1}{v_j - 1} \cdot \sum_{k=1}^{v_j} \left(\Phi_{jk}^{(m)} - \overline{\Phi}_j^{(m)}\right)^2\right)^{\frac{1}{2}} \end{pmatrix} \qquad (18).$$

5. Classes in which the mean values for the variables PA, SA, TA or BL Front Pressure are too far away from the corresponding setting parameters are picked out. Therefore, in these classes it was not possible to reach the setting values.

STATISTICAL CHARACTERISTIC VARIABLES FOR THE GIVEN CLASSES AND THEIR GRAPHIC REPRESENTATION

Apart from the arithmetic mean values and the empirical standard deviations which were determined for the individual classes, a common standard deviation s is also determined according to

$$s = \begin{pmatrix} \left(\frac{1}{v-1} \cdot \sum_{j=1}^{u} \left(v_j - 1\right) s_j^{(1)^2}\right)^{\frac{1}{2}} \\ \vdots \\ \left(\frac{1}{v-1} \cdot \sum_{j=1}^{u} \left(v_j - 1\right) s_j^{(m)^2}\right)^{\frac{1}{2}} \end{pmatrix} \quad (19)$$

where u stands for the number of classes (here 205) and v stands for the sum of v_j, i.e. v is the number of all the measured values used (here 38915).

LINEAR REGRESSION MODELS FOR FUNCTION APPROXIMATIONS

For each measured variable (item of measurement data) $\Phi^{(i)}$ (i=1,2,...,m), a linear regression model is calculated on the basis of the arithmetic mean over the classes in dependence on the quadratic combination of the four setting parameters. In the following representation, $x \in \mathbf{R}^4$, where

$x^{(1)}$: Primary Air (PA)
$x^{(2)}$: Secondary Air (SA)
$x^{(3)}$: Tertiary Air (TA)
$x^{(4)}$: Black Liquor (BL) Front Pressure

applies. $u \in \mathbf{N}$ denotes the number of classes. Each measured variable $\Phi^{(i)}$ is modeled by

$$\Phi^{(i)}(x, \omega) = a_i^T r(x) + e_i(\omega) \quad (20)$$

with $a_i \in \mathbf{R}^{15}$. Here the following applies:

$$r : \mathbf{R}^4 \rightarrow \mathbf{R}^{15} \quad (21)$$

$$(\zeta_1, \zeta_2, \zeta_3, \zeta_4)^T \rightarrow (1, \zeta_1, \zeta_2, \zeta_3, \zeta_4, \zeta_1^2, \zeta_2^2, \zeta_3^2, \zeta_4^2, \zeta_1\zeta_2, \zeta_1\zeta_3, \zeta_1\zeta_4, \zeta_2\zeta_3, \zeta_2\zeta_4, \zeta_3\zeta_4)^T \quad (22),$$

i.e. polynomials of the second degree are adapted to the measurement data, and

$$e_i : \Omega \rightarrow \mathbf{R} \quad (23)$$

is a random variable with the expected value 0.

The vector a_i is determined by the method of least squares, but the arithmetic means $\left(x_j, \Phi_{jk}^{(i)}\right)^T$ are used instead of the original data sets $\left(x_j, \overline{\Phi}_j^{(i)}\right)^T$.

This procedure is suitable, since linear regression models estimate in particular expected values. This results in the following minimization problem:

$$\min_{a_i \in \mathbf{R}^{15}} \left\{ \left\| \begin{pmatrix} \overline{\Phi}_1^{(i)} \\ \vdots \\ \overline{\Phi}_u^{(i)} \end{pmatrix} - \begin{pmatrix} r(x_1)^T \\ \vdots \\ r(x_u)^T \end{pmatrix} \cdot \begin{pmatrix} a_i^{(1)} \\ \vdots \\ a_i^{(15)} \end{pmatrix} \right\|_2^2 \right\} \quad (24).$$

Let $\overline{a_i}$ be the optimum point of the quadratic minimization problem from equation (24). Furthermore, the following applies:

$$\hat{y}_i := \begin{pmatrix} r(x_1)^T \\ \vdots \\ r(x_u)^T \end{pmatrix} \cdot \begin{pmatrix} \overline{a}_i^{(1)} \\ \vdots \\ \overline{a}_i^{(15)} \end{pmatrix} \in \mathbf{R}^u \quad (25),$$

$$\overline{y}_i := \frac{1}{u} \cdot \sum_{j=1}^{u} \overline{\Phi}_j^{(i)} \in \mathbf{R} \quad (26).$$

To validate the regression theorem, a coefficient of determination R^2 is calculated according to

$$R^2 := \frac{\sum_{j=1}^{u}\left(\hat{y}_i^{(j)} - \overline{y}_i\right)^2}{\sum_{j=1}^{u}\left(\overline{\Phi}_j^{(i)} - \overline{y}_i\right)^2} = \frac{\hat{y}_i^T \hat{y}_i - u\overline{y}_i^2}{\overline{\Phi}^{(i)T}\overline{\Phi}^{(i)} - u\overline{y}_i^2} \quad (27)$$

with

$$\overline{\Phi}^{(i)} = \begin{pmatrix} \overline{\Phi}_1^{(i)} \\ \vdots \\ \overline{\Phi}_u^{(i)} \end{pmatrix} \quad (28).$$

The closer R^2_i is to 1, the better the dependent variable is represented by the independent variables $\left(0 \le R_i^2 \le 1\right)$.

In addition, a maximum $E^{(i)}_{max}$ for an absolute value of the deviation of the data from the model is specified as

$$E_{max}^{(i)} := \max_{j=1,\ldots,u} \left\{\left|\overline{\Phi}_j^{(i)} - \hat{y}_i^{(j)}\right|\right\} \quad (29).$$

$E^{(i)}_{90\%}$ is that value below which at least 90% of the absolute values of the deviations of the data from the model lie. By analogy with this, $E^{(i)}_{80\%}$ is that value below which at least 80% of the absolute values of the deviations of the data from the model lie. With the optimum point $\overline{a_i}$ of the minimization problem according to equation (24), a model $\tilde{\Phi}^{(i)}$ of the expected value of the measured variable $\Phi^{(i)}$ can be specified as

$$\tilde{\Phi}^{(i)} := \mathbf{R}^n \rightarrow \mathbf{R} \qquad (30),$$

$$x \rightarrow \overline{a}_i^T r(x) \qquad (31).$$

In particular, the gradient $\nabla\tilde{\Phi}^{(i)}$ can be analytically specified by

$$\nabla\tilde{\Phi}^{(i)}(x) = \frac{dr}{dx}(x) \cdot \overline{a}_i \quad \text{for all} \quad x \in \mathbf{R}^n \qquad (32).$$

<u>Patent claims</u>

1. A method for designing a technical system,

a) in which measurement data of a predetermined system are described on the basis of a substitute model;

b) in which a numerical value for the quality of the substitute model is determined by comparing the measurement data of the predetermined system with data determined by the substitute model;

c) in which the substitute model is adapted from the numerical value for the quality to be of as high a quality as possible;

d) in which the substitute model adapted with regard to its quality is used for designing the technical system.

2. The method as claimed in claim 1, in which the substitute model is a regression model.

3. The method as claimed in claim 1 or 2, in which the quality is determined on the basis of a mean square deviation of the measurement data from the data determined by the substitute model.

4. The method as claimed in one of the preceding claims, in which the measurement data are sorted according to their quality, with respect to the deviation of the latter from the data determined by the substitute model, and a predetermined number of n% of the worst measurement data are picked out.

5. The method as claimed in claim 4, in which the n% of the worst measurement data are not picked out

09/857281
JC18 Rec'd PCT/PTO 01 JUN 2001

if they lie in a continuous range.

6. The method as claimed in one of the preceding claims, in which the amount of measurement data is reduced in the course of a preprocessing operation.

7. The method as claimed in claim 6, in which the preprocessing operation comprises a classification of the measurement data.

8. The method as claimed in one of the preceding claims, in which the data obtained by means of designing are used for controlling a technical plant.

9. The method as claimed in claim 8, for the online adaptation of the control for the technical plant.

10. An arrangement for designing a technical system, with a processor unit which is set up in such a way that

a) measurement data of a predetermined system are described on the basis of a substitute model;
b) a numerical value for the quality of the substitute model is determined by comparing the measurement data of the predetermined system with data determined by the substitute model;
c) the substitute model is adapted from the numerical value for the quality to be of as high a quality as possible;
d) the substitute model adapted with regard to its quality is used for designing the technical system.

GR 98 P 5868

Abstract

Method and arrangement for designing a technical system

To achieve the object, a method for designing a technical system in which measurement data of a predetermined system are described on the basis of a substitute model is specified. A numerical value for the quality of the substitute model is determined by comparing the measurement data of the predetermined system with data determined by the substitute model. On the basis of the numerical value for the quality, the substitute model is adapted to be of as high a quality as possible. The substitute model adapted with regard to its quality is used for designing the technical system.

FIG 1

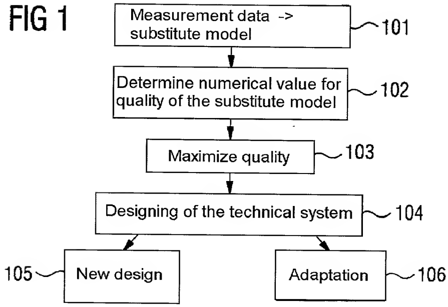
Measurement data -> substitute model
101
Determine numerical value for quality of the substitute model
102
Maximize quality
103
Designing of the technical system
104
105
New design
Adaptation
106

FIG 2

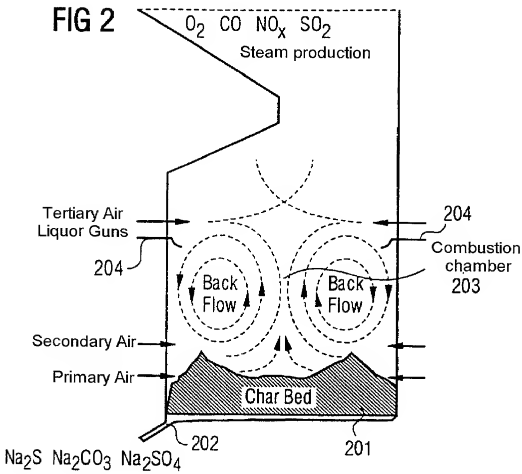
O_2 CO NO_x SO_2
Steam production
Tertiary Air
Liquor Guns
204
204
Combustion chamber
203
Back Flow
Back Flow
Secondary Air
Primary Air
Char Bed
202
201
Na_2S Na_2CO_3 Na_2SO_4

FIG 3

Input variables		
	Measured variable	Description
1	FI 7081	BL Flow
2	QI 7082 A	Dry Solids Content
3	FIC 7280 X	PA Primary Air
4	FIC 7281 X	SA Secondary Air
5	FIC 7282 X	TA Tertiary Air
6	PI 7283	PA Pressure
7	PI 7284	SA Pressure
8	PHI 7285	TA Pressure
9	TIC 7288 X	PA Temperature
10	TIC 7289 X	SA Temperature
11	PIC 7305 X	Press Induced Draft
12	HO 7338	Oil Valve
13	TI 7347	BL Temperature
14	PIC 7349 X	BL Front Pressure
15	PIC 7351 X	BL Back Pressure

FIG 4

Manipulated variables		
	Measured variable	Description
1	FIC 7280 X	PA Primary Air
2	FIC 7281 X	SA Secondary Air
3	FIC 7282 X	TA Tertiary Air
4	PIC 7349 X	BL Front Pressure

FIG 5

Output variables		
	Measured variable	Description
1	TIC 7249 X	Steam Temperature
2	FI 7250	Steam Production
3	QI 7322	O_2
4	TI 7323	Smoke Temperature
5	QI 7331	H_2S
6	QI 7332	SO_2
7	QIC 7333 X	CO
8	QIC 7370 X	Spec. Weight of Green Liquor
9	QI 7531	NO
10	IBM 8096	Reduction Efficiency
11	IBM 8109	PH Value
12	TI 7352	Bed Temperature
13	IBM 8015	$NaOH$
14	IBM 8016	Na_2S
15	IBM 8017	Na_2CO_3

Declaration and Power of Attorney For Patent Application
Erklärung Für Patentanmeldungen Mit Vollmacht
German Language Declaration

Als nachstehend benannter Erfinder erkläre ich hiermit an Eides Statt:

dass mein Wohnsitz, meine Postanschrift, und meine Staatsangehörigkeit den im Nachstehenden nach meinem Namen aufgeführten Angaben entsprechen,

dass ich, nach bestem Wissen der ursprüngliche, erste und alleinige Erfinder (falls nachstehend nur ein Name angegeben ist) oder ein ursprünglicher, erster und Miterfinder (falls nachstehend mehrere Namen aufgeführt sind) des Gegenstandes bin, für den dieser Antrag gestellt wird und für den ein Patent beantragt wird für die Erfindung mit dem Titel:

Verfahren und Anordnung zum Entwurf eines technischen Systems

deren Beschreibung

(zutreffendjhaes ankreuzen)

☒ hier beigefügt ist.

☐ am ____________ als
PCT internationale Anmeldung
PCT Anmeldungsnummer ____________
Eingereicht wurde und am ____________
Abgeändert wurde (falls tatsächlich abgeändert).

Ich bestätige hiermit, dass ich den Inhalt der obigen Patentanmeldung einschliesslich der Ansprüche durchgesehen und verstanden habe, die eventuell durch einen Zusatzantrag wie oben erwähnt abgeändert wurde.

Ich erkenne meine Pflicht zur Offenbarung irgendwelcher Informationen, die für die Prüfung der vorliegenden Anmeldung in Einklang mit Absatz 37, Bundesgesetzbuch, Paragraph 1.56(a) von Wichtigkeit sind, an.

Ich beanspruche hiermit ausländische Prioritätsvorteile gemäss Abschnitt 35 der Zivilprozessordnung der Vereinigten Staaten, Paragraph 119 aller unten angegebenen Auslandsanmeldungen für ein Patent oder eine Erfindersurkunde, und habe auch alle Auslandsanmeldungen für ein Patent oder eine Erfindersurkunde nachstehend gekennzeichnet, die ein Anmeldedatum haben, das vor dem Anmeldedatum der Anmeldung liegt, für die Priorität beansprucht wird.

As a below named inventor, I hereby declare that

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

____

the specification of which

(check one)

☐ is attached hereto.

☐ was filed on ____________ as
PCT international application
PCT Application No. ____________
and was amended on ____________
(if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a)

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Form PTO-FB-240 (8-83)

Patent and Trademark Office-U.S. DEPARTMENT OF COMMERCE

German Language Declaration

Prior foreign appplications
Priorität beansprucht

Priority Claimed

(Number) (Nummer)	(Country) (Land)	(Day Month Year Filed) (Tag Monat Jahr eingereicht)	Yes Ja	No Nein
198 55 873.2	Germany	03. Dezember 1998	☒	☐
			☐	☐
			☐	☐

Ich beanspruche hiermit gemäss Absatz 35 der Zivilprozessordnung der Vereinigten Staaten, Paragraph 120, den Vorzug aller unten aufgeführten Anmeldungen und falls der Gegenstand aus jedem Anspruch dieser Anmeldung nicht in einer früheren amerikanischen Patentanmeldung laut dem ersten Paragraphen des Absatzes 35 der Zivilprozeßordnung der Vereinigten Staaten, Paragraph 122 offenbart ist, erkenne ich gemäss Absatz 37, Bundesgesetzbuch, Paragraph 1.56(a) meine Pflicht zur Offenbarung von Informationen an, die zwischen dem Anmeldedatum der früheren Anmeldung und dem nationalen oder PCT internationalen Anmeldedatum dieser Anmeldung bekannt geworden sind.

I hereby claim the benefit under Title 35. United States Code. §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §122, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occured between the filing date of the prior application and the national or PCT international filing date of this application

(Application Serial No.) (Anmeldeseriennummer)	(Filing Date) (Anmeldedatum)	(Status) (patentiert, anhängig, aufgegeben)	(Status) (patented, pending, abandoned)

(Application Serial No.) (Anmeldeseriennummer)	(Filing Date) (Anmeldedatum)	(Status) (patentiert, anhängig, aufgeben)	(Status) (patented, pending, abandoned)

Ich erkläre hiermit, dass alle von mir in der vorliegenden Erklärung gemachten Angaben nach meinem besten Wissen und Gewissen der vollen Wahrheit entsprechen, und dass ich diese eidesstattliche Erklärung in Kenntnis dessen abgebe, dass wissentlich und vorsätzlich falsche Angaben gemäss Paragraph 1001, Absatz 18 der Zivilprozessordnung der Vereinigten Staaten von Amerika mit Geldstrafe belegt und/oder Gefangnis bestraft werden koennen, und dass derartig wissentlich und vorsätzlich falsche Angaben die Gültigkeit der vorliegenden Patentanmeldung oder eines darauf erteilten Patentes gefährden können.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

German Language Declaration

VERTRETUNGSVOLLMACHT: Als benannter Erfinder beauftrage ich hiermit den nachstehend benannten Patentanwalt (oder die nachstehend benannten Patentanwälte) und/oder Patent-Agenten mit der Verfolgung der vorliegenden Patentanmeldung sowie mit der Abwicklung aller damit verbundenen Geschäfte vor dem Patent- und Warenzeichenamt: *(Name und Registrationsnummer anführen)*

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. *(list name and registration number)*

And I hereby appoint

Messrs. John D. Simpson (Registration No. 19,842) Lewis T. Steadman (17,074), William C. Stueber (16,453), P. Phillips Connor (19,259), Dennis A. Gross (24,410), Marvin Moody (16,549), Steven H. Noll (28,982), Brett A. Valiquet (27,841), Thomas I. Ross (29,275), Kevin W. Guynn (29,927), Edward A Lehmann (22,312), James D Hobart (24,149), Robert M. Barrett (30,142), James Van Santen (16,584), J. Arthur Gross (13,615), Richard J. Schwarz (13,472) and Melvin A. Robinson (31,870), David R. Metzger (32,919), John R. Garrett (27,888) all members of the firm of Hill, Steadman & Simpson, A Professional Corporation.

17

Telefongespräche bitte richten an: *(Name und Telefonnummer)*

Direct Telephone Calls to: *(name and telephone number)*

312/876-0200
Ext. ______________

Postanschrift:

Send Correspondence to.

HILL, STEADMAN & SIMPSON
A Professional Corporation
85th Floor Sears Tower, Chicago, Illinois 60606

Voller Name des einzigen oder ursprünglichen Erfinders:	Full name of sole or first inventor:
SCHÄFFLER, Stefan	
Unterschrift des Erfinders / Datum: [signature] 11.11.99	Inventor's signature / Date
Wohnsitz: D-86199 Augsburg, Germany DEX	Residence
Staatsangehörigkeit: Bundesrepublik Deutschland	Citizenship
Postanschrift: Paul-Lincke-Str. 15	Post Office Address
D-86199 Augsburg Bundesrepublik Deutschland	
Voller Name des zweiten Miterfinders (falls zutreffend):	Full name of second joint inventor, if any:
STURM, Thomas	
Unterschrift des Erfinders / Datum: [signature] 11.11.1999	Second Inventor's signature / Date
Wohnsitz: D-81673 München, Germany DEX	Residence
Staatsangehörigkeit: Bundesrepublik Deutschland	Citizenship
Postanschrift: Schlüsselbergstr. 16	Post Office Address
D-81673 München Bundesrepublik Deutschland	

(Bitte entsprechende Informationen und Unterschriften im Falle von dritten und weiteren Miterfindern angeben).

(Supply similar information and signature for third and subsequent joint inventors).

Form PTO-FB-240 (8-83) Patent and Trademark Office-U.S. Department of COMMERCE